

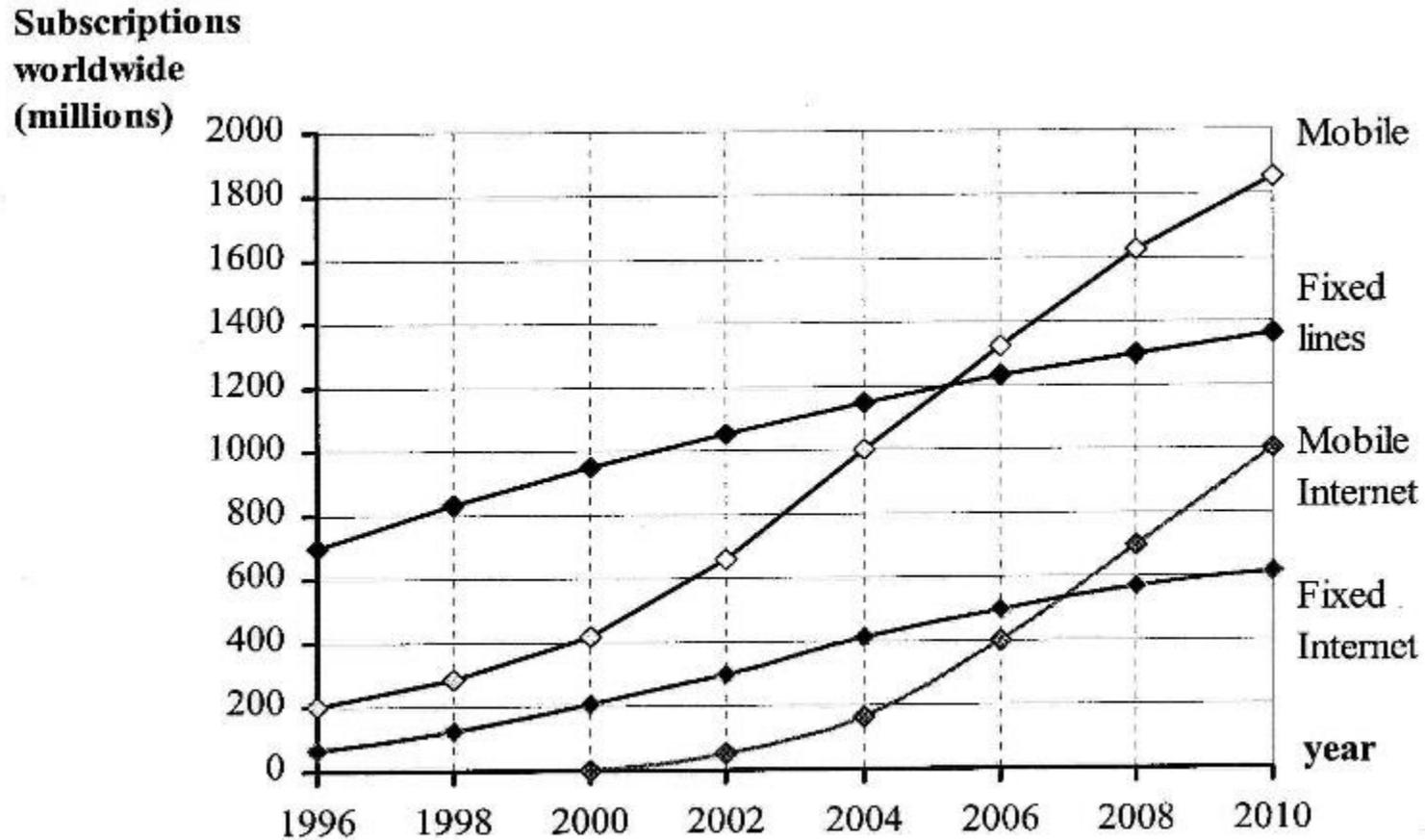
Asean Factory

Cellular Mobile Communications
GSM / GPRS / UMTS / LTE / 5G

Prof. Emil NOVAKOV

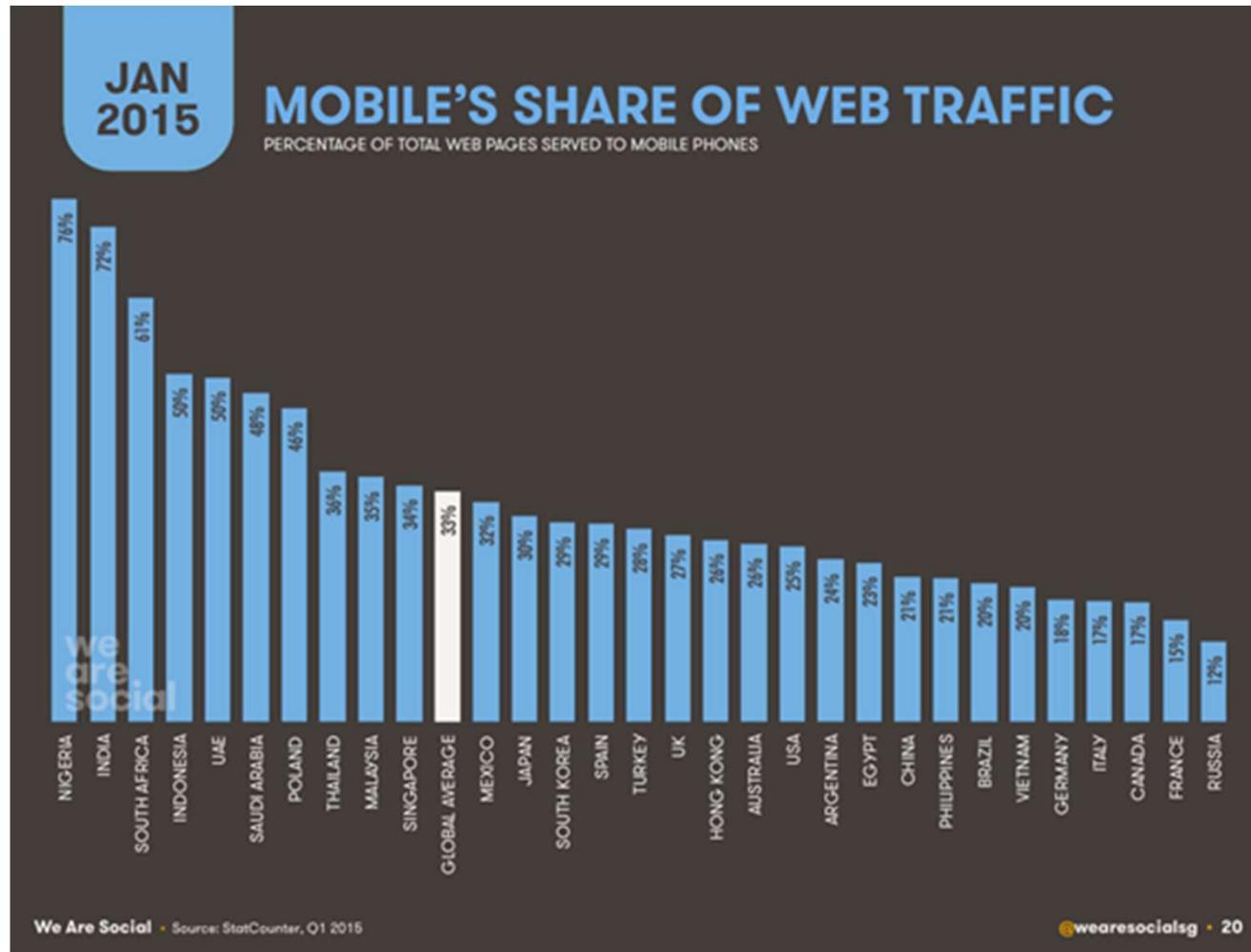
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The Telecommunications World



« Instant access to all information whatever you are »

Mobile Internet

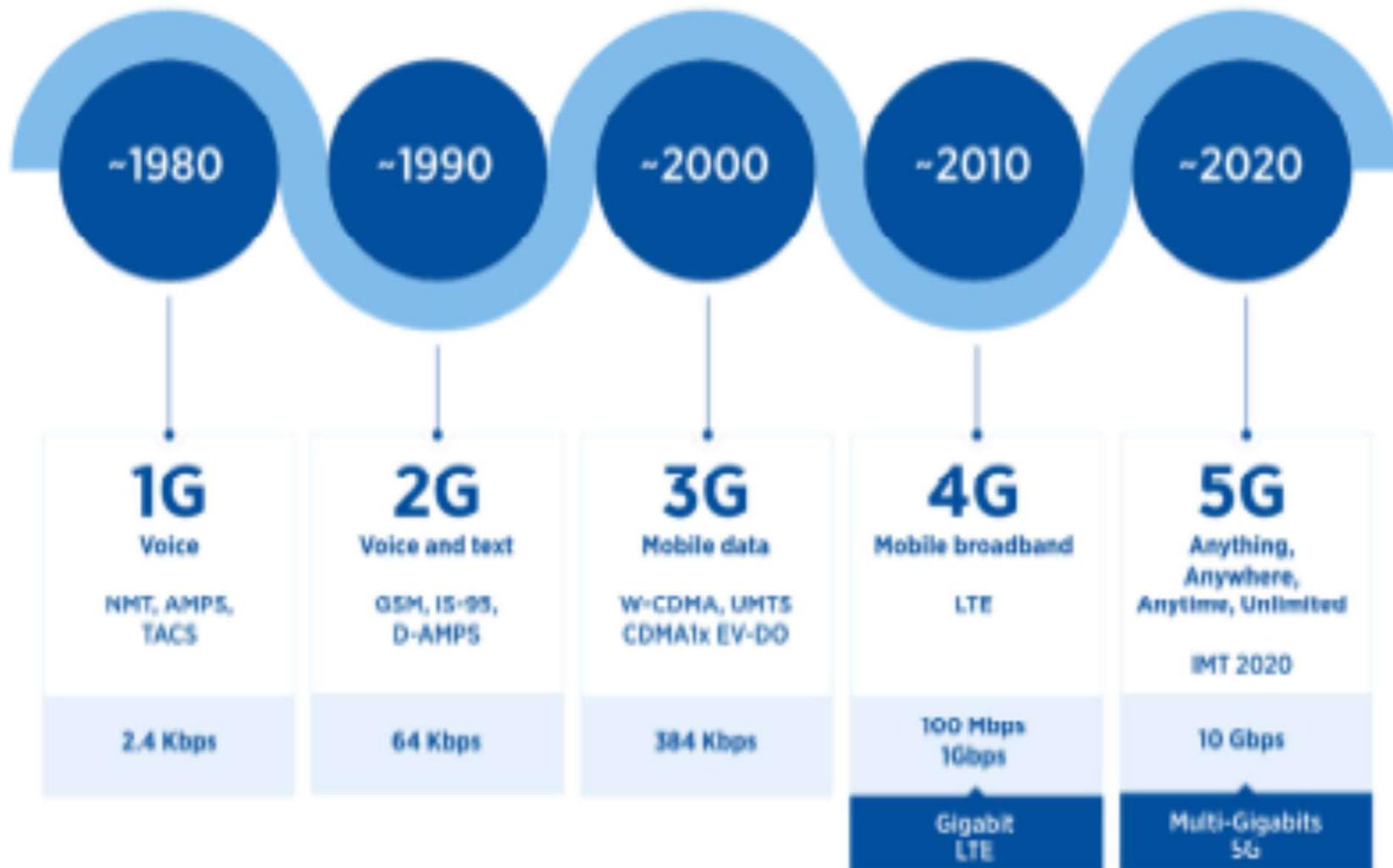


31.03.2022

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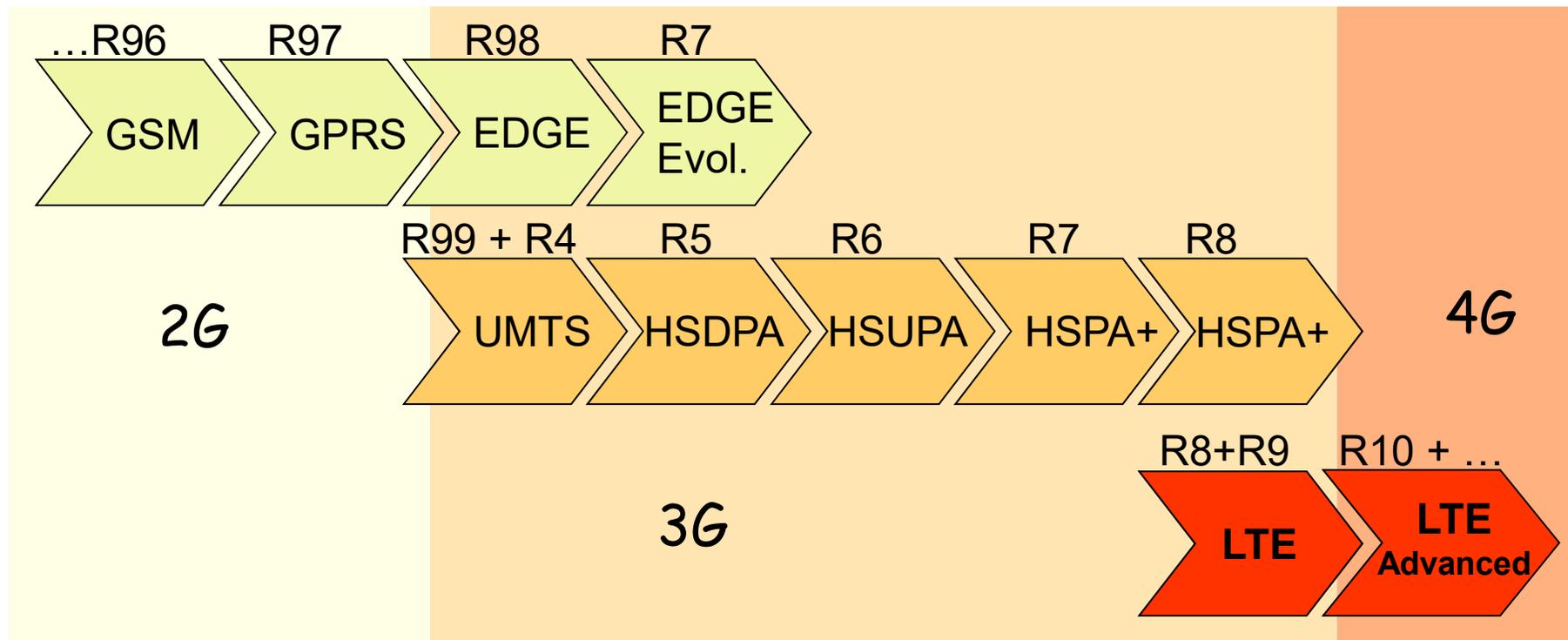
40 Years of Cellular Communications : 5 Generations



From 1G to 4G

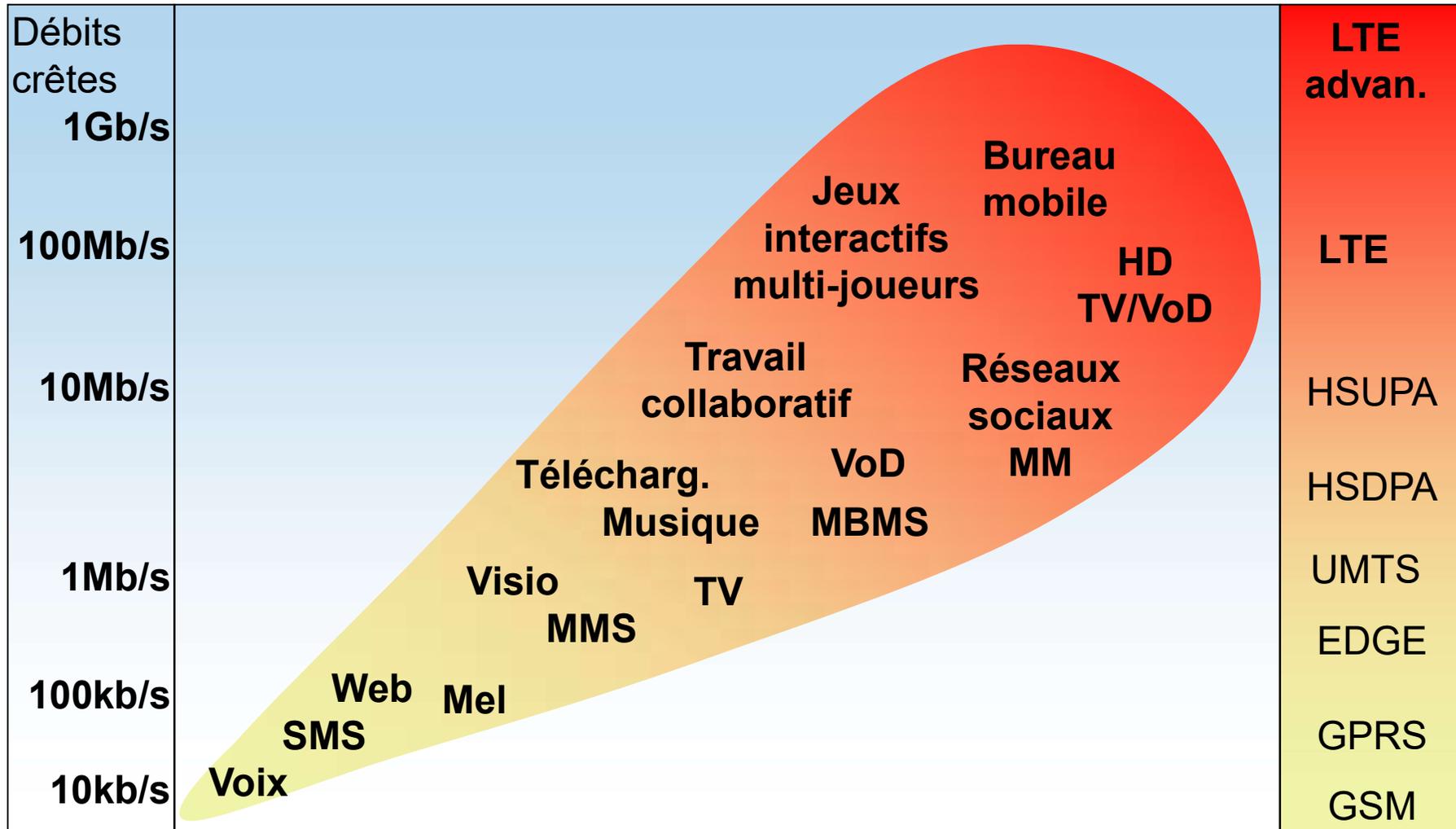
1G

Standardisation ETSI

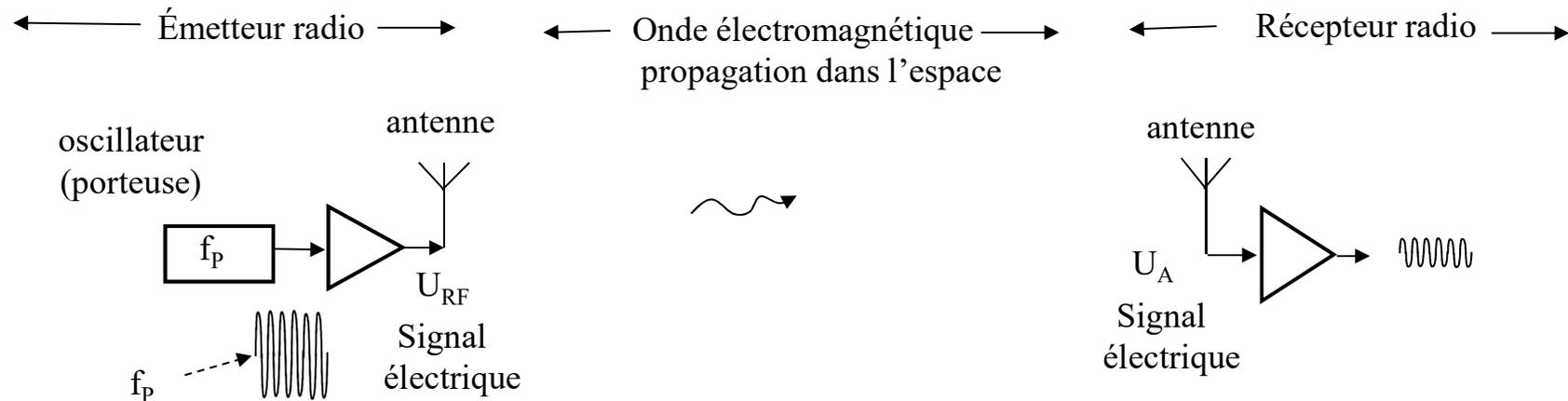


Mobile phone generation = radio communication technology + spectrum + type of access to data & voice networks

Mobile services



Basic principle of radio communications



Onde (champ) électromagnétique : phénomène physique oscillatoire qui se propage dans l'espace vide et qui transporte de l'énergie

Antenne : transducteur signal électrique \leftrightarrow champ électromagnétique

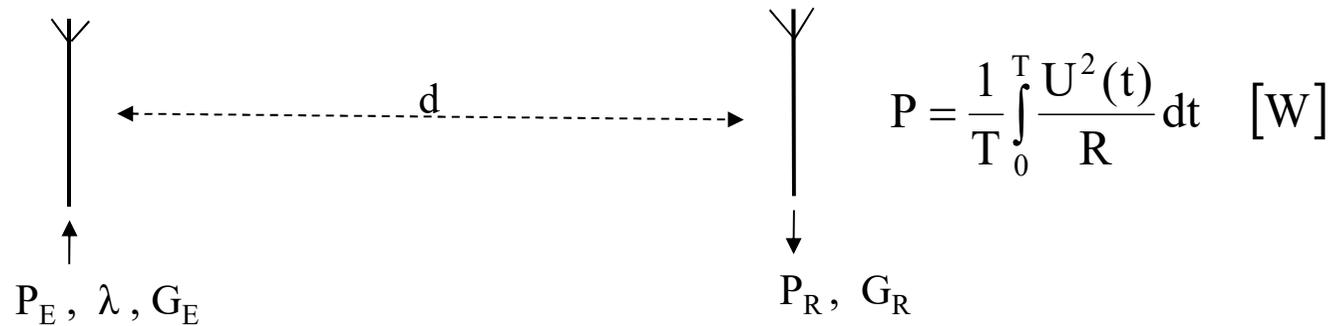
Communication radio : transfert d'énergie entre l'émetteur et le récepteur par l'intermédiaire d'une onde électromagnétique

Transfer d'énergie – transfert d'information

Rem.: l'énergie minimale correspondante au transfert d'un bit d'information est $E_{\text{MIN}} = kT \ln(2)$

Radio propagation

Free space radio propagation (*Friis law*)

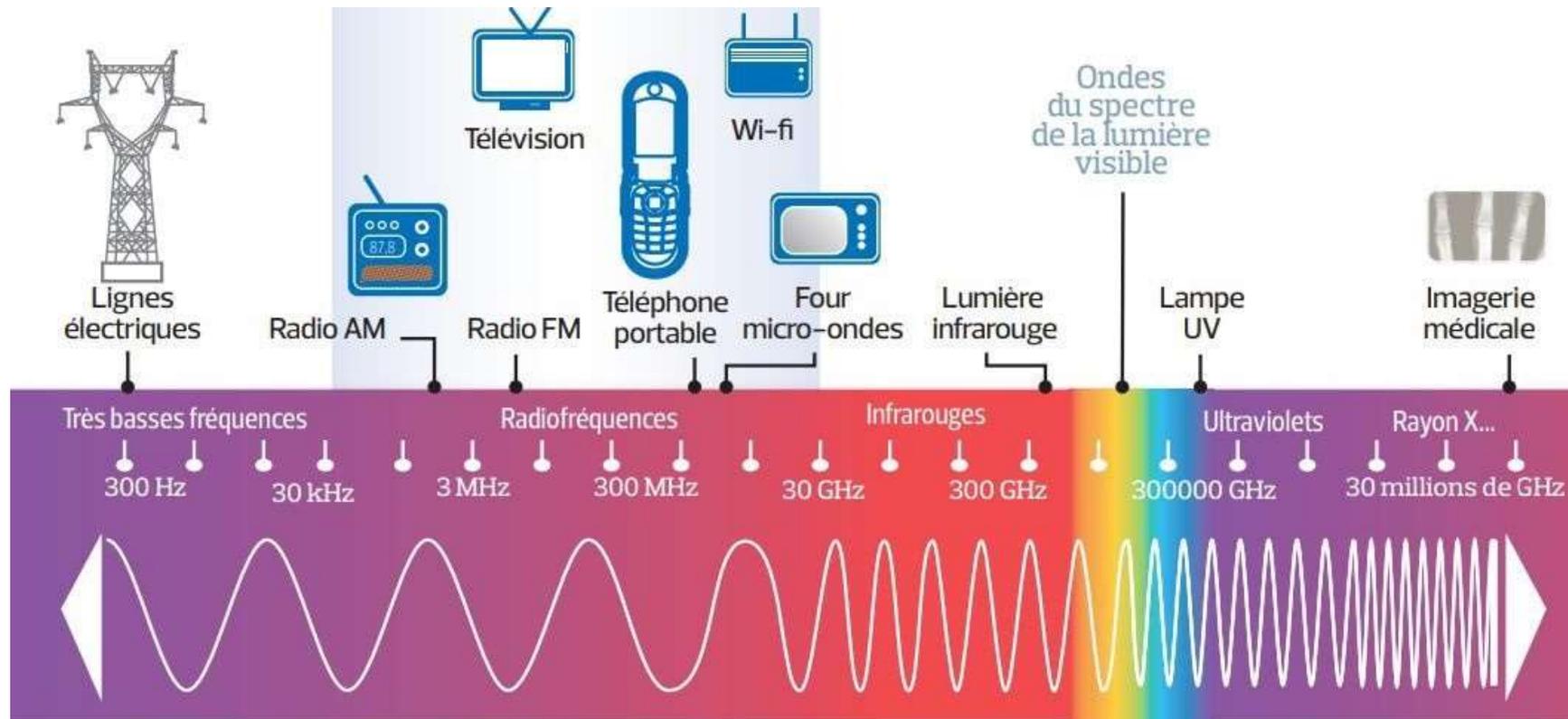


$$\lambda = \frac{c}{f} \quad \lambda[m], \quad f[\text{Hz}], \quad c \approx 3 * 10^8 [m/s] \quad \lambda[m] = \frac{300}{f[\text{MHz}]}$$

$$P_R = \frac{P_E G_E G_R}{[4\pi d / \lambda]^2} = \frac{P_E G_E G_R}{[(4\pi / c) d f]^2} \quad G_{\text{vide}} = \frac{G_E G_R}{[(4\pi / c) d f]^2} \quad A_{\text{vide}} = \frac{1}{G} = k f^2 d^2$$

Antenna →
Free space →

Electromagnetic waves



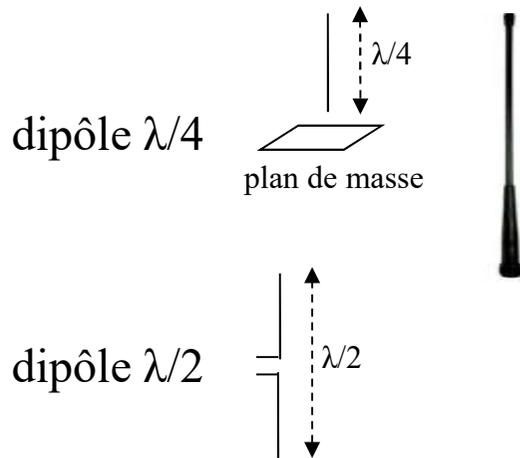
Rem.: the human eye is a "radio receiver"

Antennas

Antenne : transducteur signal électrique RF \leftrightarrow champ électromagnétique

Transducteur réversible : émission et réception

La dimension de l'antenne dépend de la fréquence du signal à émettre



Fréquences et longueurs d'ondes typiques:

$$f_p = 3\text{kHz} \quad \lambda = 100 \text{ km} \quad (\text{voix})$$

$$f_p = 1\text{MHz} \quad \lambda = 300 \text{ m} \quad (\text{radio AM})$$

$$f_p = 100\text{MHz} \quad \lambda = 3 \text{ m} \quad (\text{radio FM})$$

$$f_p = 300\text{MHz} \quad \lambda = 1 \text{ m} \quad (\text{TV - TNT})$$

$$f_p = 900\text{MHz} \quad \lambda = 33 \text{ cm} \quad (\text{GSM - 2G})$$

$$f_p = 2.4\text{GHz} \quad \lambda = 12.5 \text{ cm} \quad (\text{WiFi})$$

$$f_p = 10\text{GHz} \quad \lambda = 3 \text{ cm} \quad (\text{TV satellite})$$



Omnidirectional versus directional antenna



$$G = 1$$



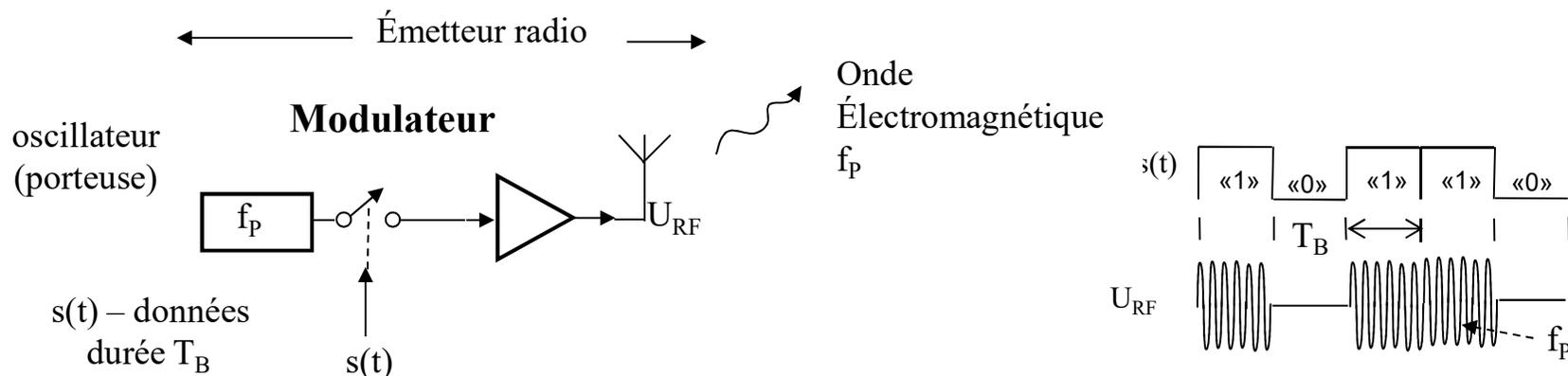
$$G > 1$$

Modulation / Multiplexing

1. Comment transmettre des signaux de basse fréquence (voix, données) par ondes électromagnétiques ?

Ex. $D = 1 \text{ Mbit/s}$, $T_B = 1/D = 1 \mu\text{s}$, $T_{\text{période}} \approx 2 \mu\text{s}$, $f \approx 500 \text{ KHz}$, $\lambda = 600 \text{ m}$

Modulation : Transfer d'un signal $s(t)$ sur une fréquence porteuse f_p



Ex. $f_p = 2.4 \text{ GHz}$, $\lambda = 12.5 \text{ cm}$

2. Comment transmettre plusieurs signaux dans le même milieu ? **Multiplexage**

RF Power (units)

Electrical signal power (definition) :

$$P = \frac{1}{T} \int_0^T \frac{U^2(t)}{R} dt \quad [\text{W}]$$

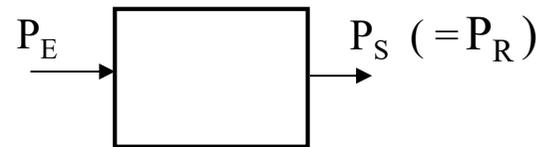
$$P[\text{W}] \rightarrow P_{\text{dBm}} = 10 \log \frac{P[\text{W}]}{10^{-3}} = 10 \log P[\text{mW}]$$

$$P = 1 \text{ mW} \rightarrow P_{\text{dBm}} = 0 \text{ dBm}$$

$$P = 100 \text{ mW} \rightarrow P_{\text{dBm}} = 20 \text{ dBm}$$

$$P = 1 \text{ W} \rightarrow P_{\text{dBm}} = 30 \text{ dBm}$$

$$P = 2 \text{ W} \rightarrow P_{\text{dBm}} = 33 \text{ dBm}$$



Power Gain :

$$G = \frac{P_S}{P_E} \quad G_{\text{dB}} = 10 \log \left(\frac{P_S}{P_E} \right)$$

Attenuation:

$$A = \frac{P_E}{P_S} = \frac{1}{G} \quad A_{\text{dB}} = 10 \log \frac{P_E}{P_S} = -G_{\text{dB}}$$

For sinusoidal signal :

$$P_{\text{sin}} = \frac{U_m^2}{2R} = \frac{U_{\text{eff}}^2}{R}$$

$$U_{\text{eff}} = U_m / \sqrt{2} \quad \text{RMS (Root Mean Square) value}$$

P increases 2 times $\rightarrow +3 \text{ dB}$

P increases 10 times $\rightarrow +10 \text{ dB}$

P decreases 2 times $\rightarrow -3 \text{ dB}$

Frequency bands

1. Radio broadcast :

- 150kHz – 40MHz (Amplitude Modulation- AM)
- 88 – 108MHz (Frequency Modulation - FM)

2. Television (TV broadcast):

- 170 – 960MHz (Image modulation-AM, sound modulation -AM or FM, now →DVB)

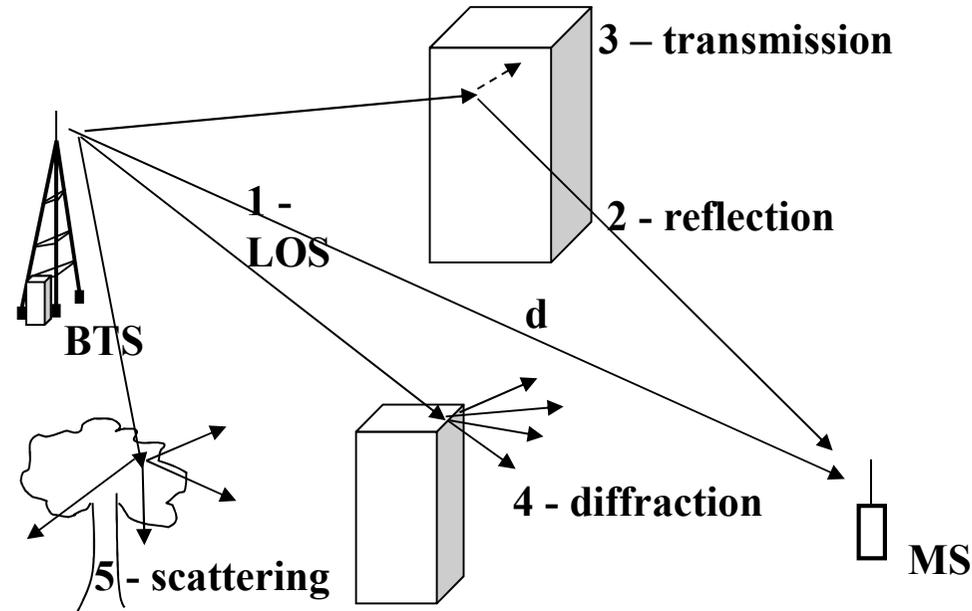
3. Radiocommunications :

- Bands in 800MHz, 900MHz, 1800MHz et 1900MHz – Cellular mobile networks (GSM/GPRS/EDGE). Communication distance : $L = 100\text{m} - 20\text{km}$
- Bands in 2GHz – 3G Cellular communications (UMTS)
- 7 GHz – 39 GHz : long distance point-to-point communications ($L = 50 - 200 \text{ km}$),
- Bands in 2.4GHz and 5.4GHz (ISM - *Industrials, Scientific and Medical*),
PAN/LAN : Bluetooth, ZigBee, Wi-Fi (Internet). $L = 1 - 100\text{m}$
- satellite communications: 4-6GHz (C band), 11-14GHz (Ku band), 20-30GHz (Ka band)

4. Special applications :

- satellite localization GPS : 1.559GHz – 1.61GHz

Real radio propagation



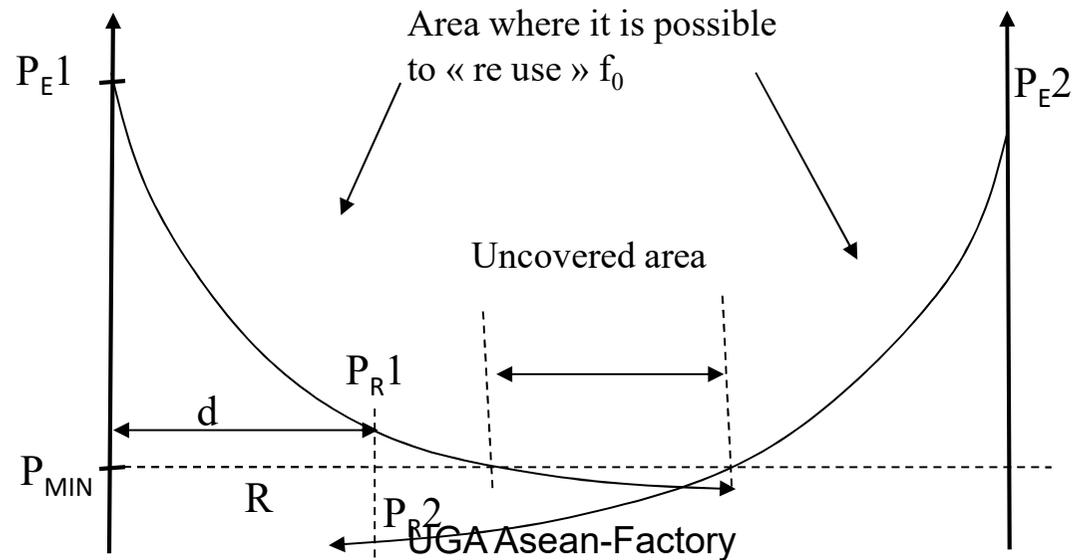
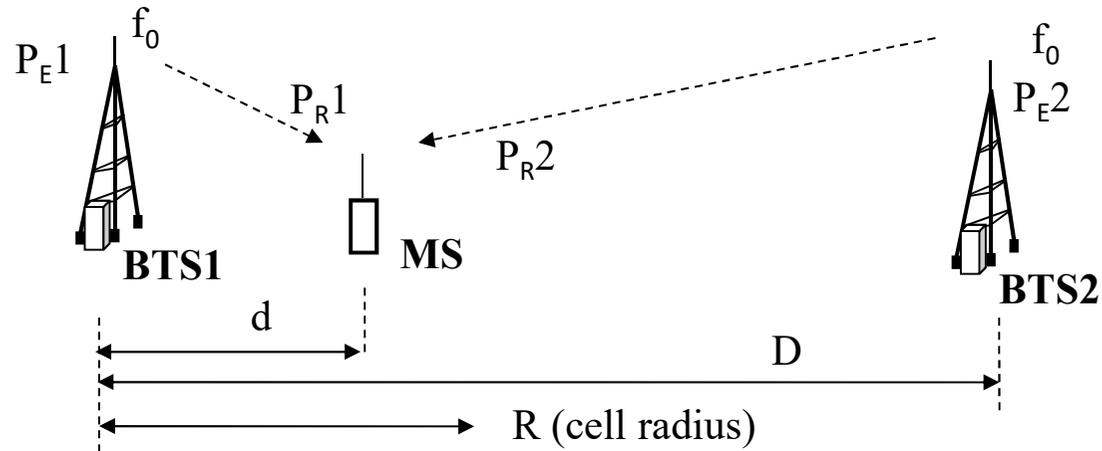
LOS Propagation (LOS - *Line Of Sight*) - 1

NLOS (*Non Line Of Sight*) propagation - 2, 3, 4, 5

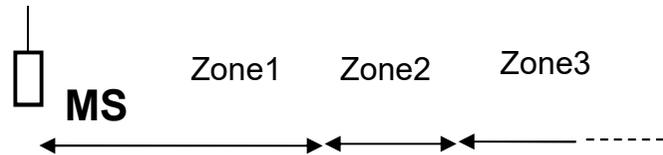
BTS – *Base Transceivers Station*, **MS** – *Mobile Station*

Friis law is not anymore valid ! $A \approx k f^2 d^n$ $n = 2 \div 5$

Cellular Principle



Frequency re-use



Zone 1: $P_R > P_{MIN}$: zone of normal reception

Zone 2: $P_R < P_{MIN}$: zone where BTS1 can be detected but cannot be received (demodulated). The signal of BTS1 is regarded as interference (I)

Zone 3: $P_R < P_{MIN}$: zone where BTS1 cannot be detected nor demodulated. It is possible to re-use f_0 .

In Zone 1 and Zone 3 we can use the same frequency for two different communications.

Zone1, Zone 3 → **cells**

Advantage of the frequency re-use:

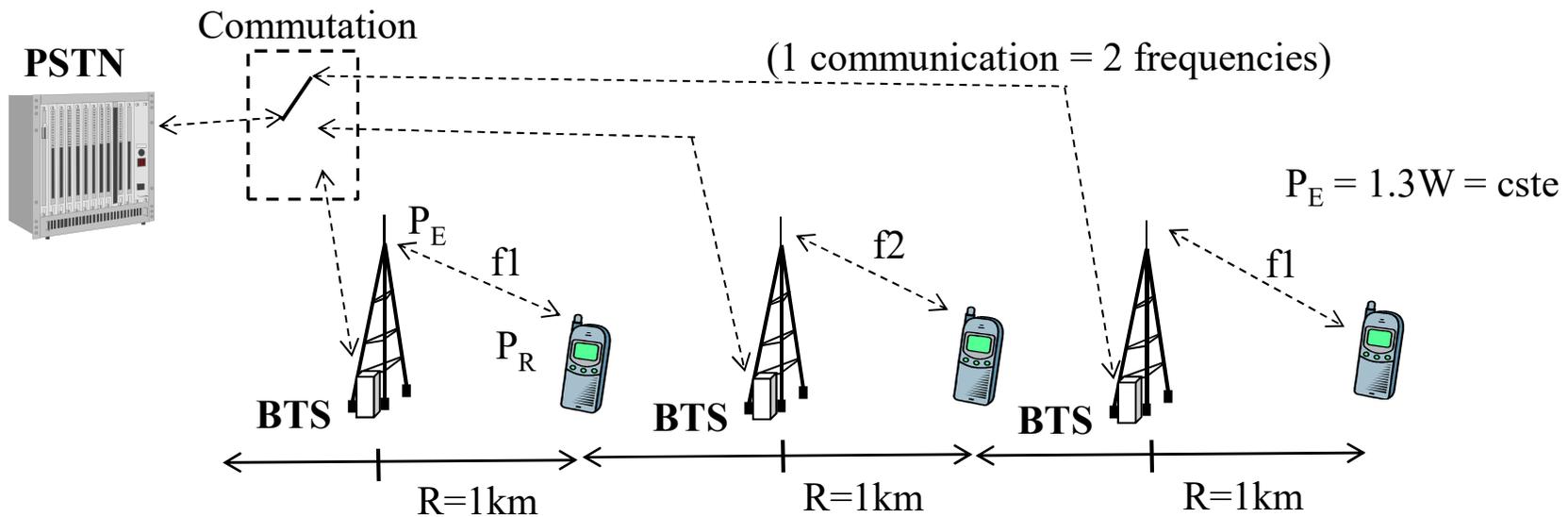
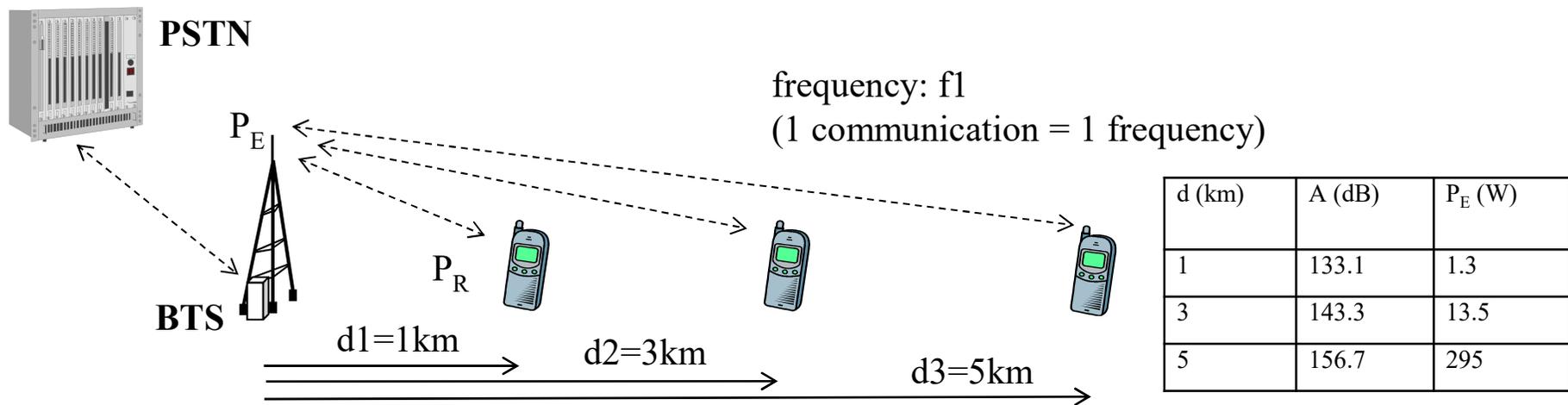
Saving in frequencies

Saving in power

Disadvantages:

if MS moves → Need for cell change

System complexity



Example :

$$f_0 = 1800\text{MHz}, P_{\text{MIN}} = -102\text{dBm},$$

$$A = 133,1 + 33,8 \log(d), d [\text{km}], P_E = A + P_R, P_{\text{EMAX}} = 33\text{dBm} = 2\text{W}$$

Cellular coverage

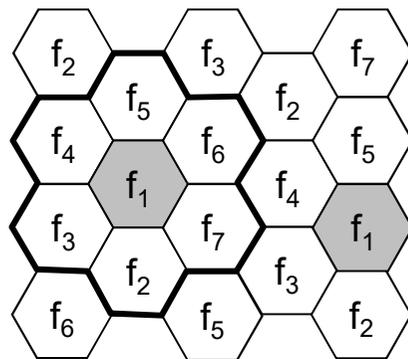
Exemple:

$$P_E = 33\text{dBm (2W)}$$

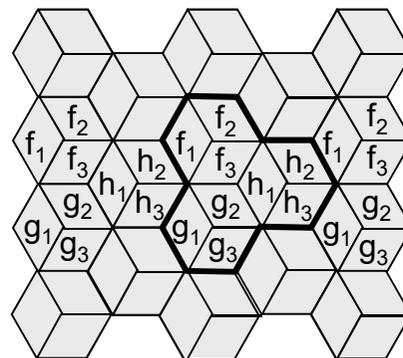
$$P_R = -102\text{dBm}$$

$$A = P_E - P_R = 135\text{dB}$$

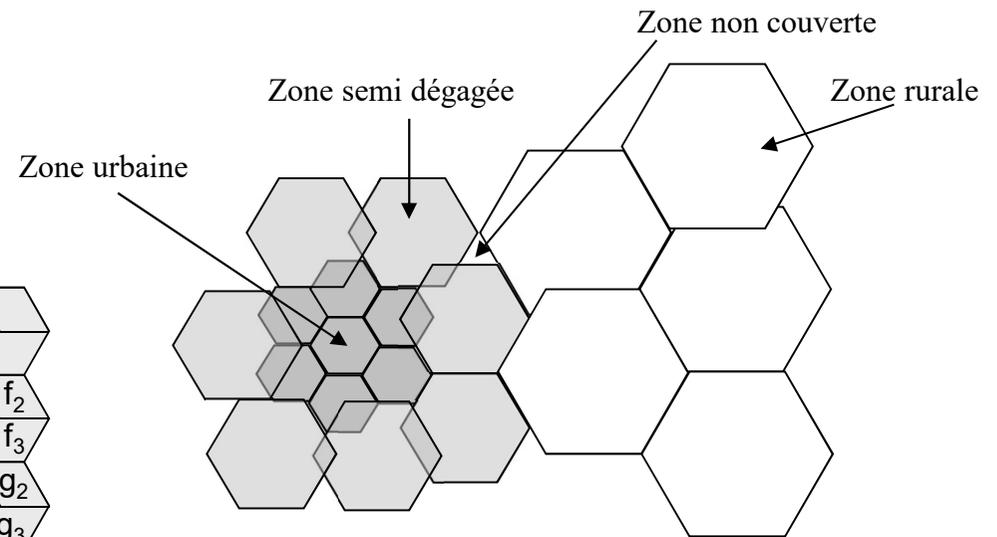
Environment	Rural	Partial visibility	Urban
900MHz	24km	17km	2km
1800MHz	15km	11km	1km



7 cell cluster



Sectorized cell



Real network

Base Station Type

Macro BTS



Mobile BTS

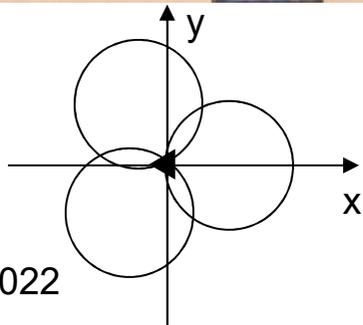


Micro / Femto BTS



GSM Cellular Network

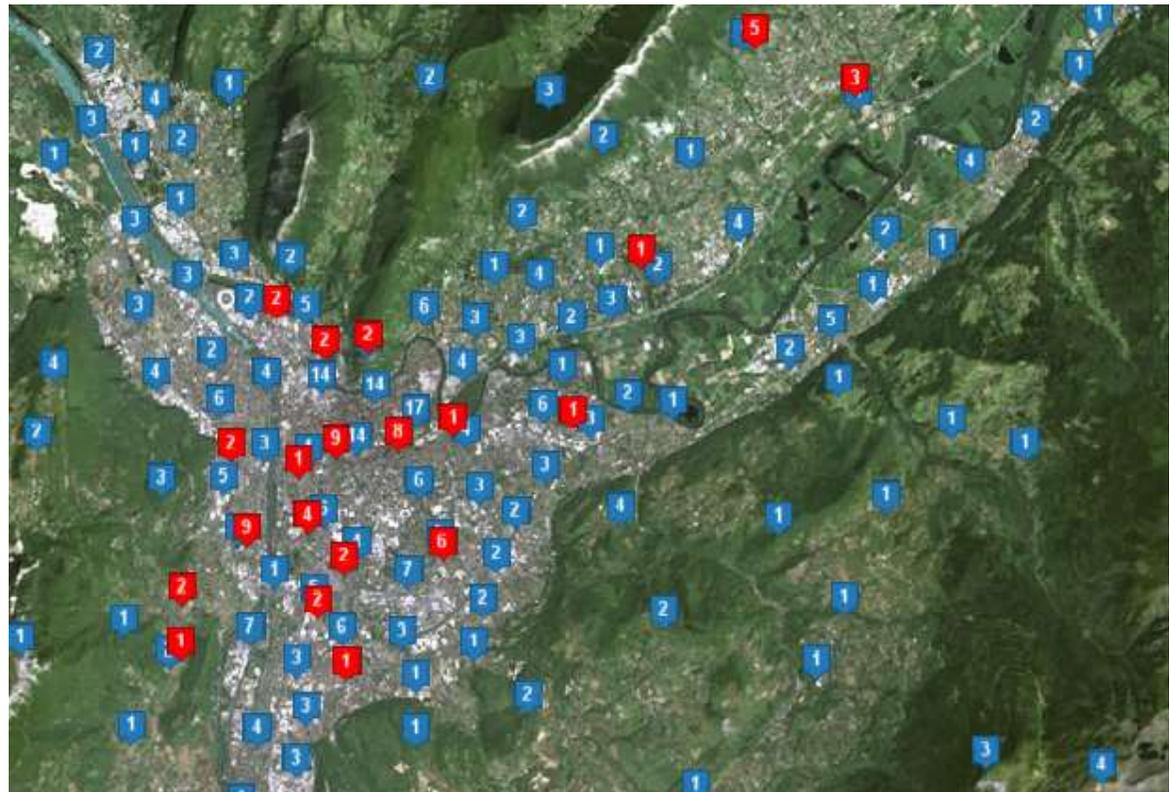
BTS (3 sectors)



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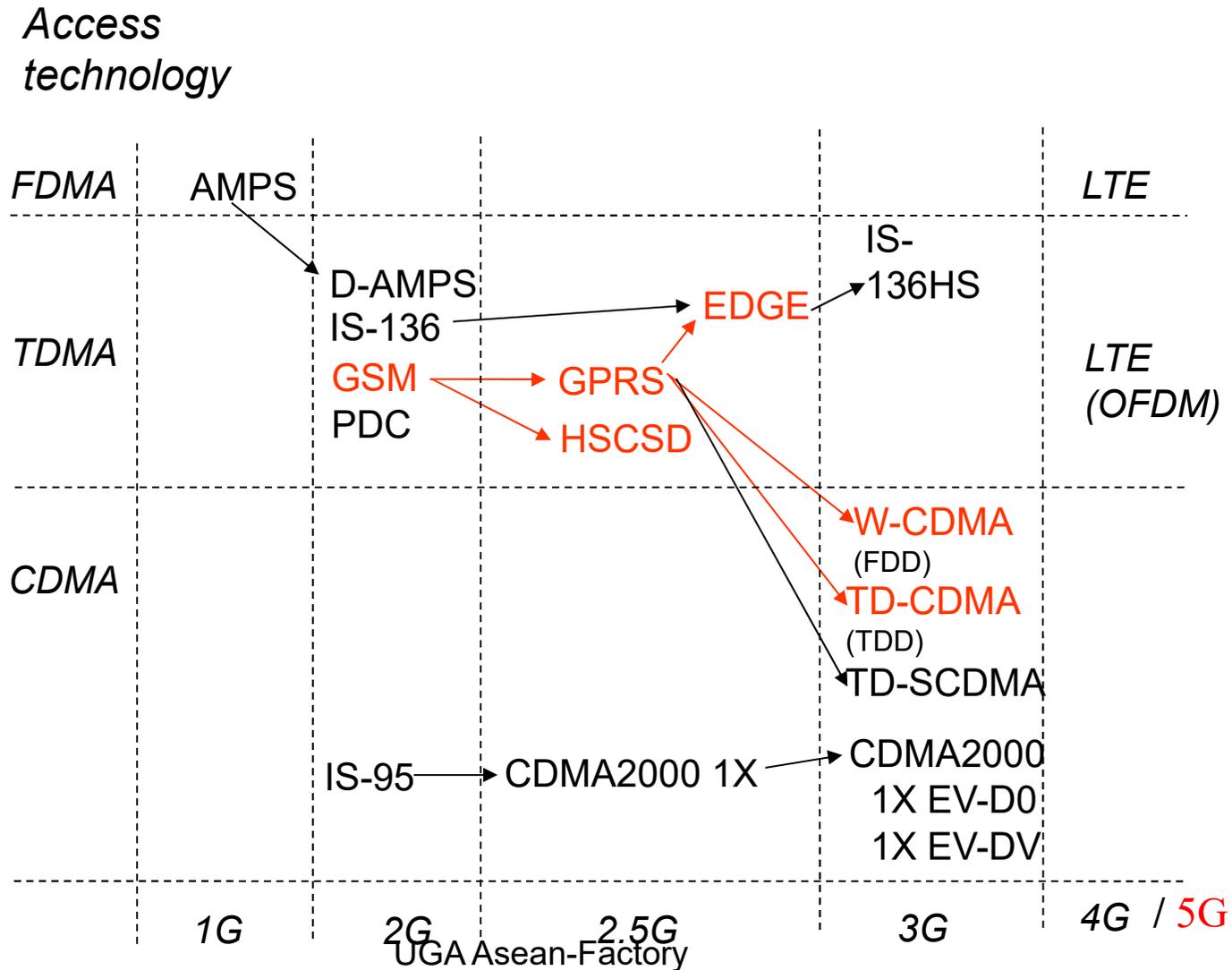
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Introduction to the GSM



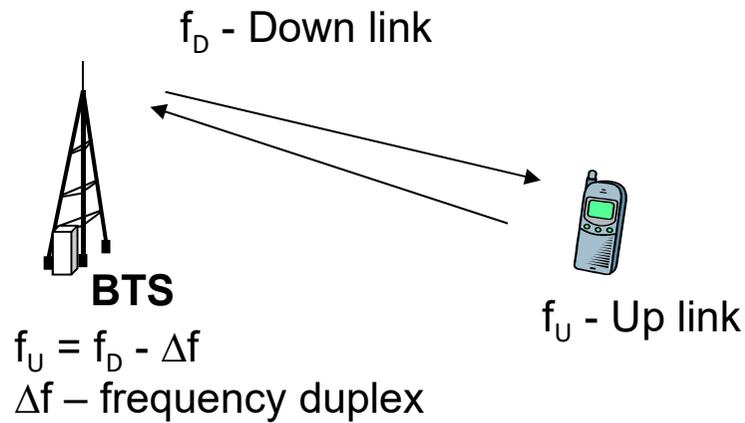
GSM History

- ~70 - Validation of the cellular concept
- AMPS - Advanced Mobile Phone System – USA , Radiocom - France
- GSM - “Groupe Spécial Mobile” (Global System for Mobile Communications)
 - 1982 – Decision of development
 - Digital System
 - Allocation of the frequencies: 890-915 / 935-960MHz
- 1987 - Selection of the radio communication technology :
 - Full digital system (data and signaling)
 - TDMA/FDD
 - Digital voice coder (RPE-LTP)
 - channel coder
 - services (voice, SMS, data 9600bit/s)
 - Communications protocols
 - Structure of the network
- 1991 - 1st experimental system
- 1992 - Beginning of the commercial exploitation
- 2000 - Introduction of the HSCSD/GPRS (~50kbit/s - 170kbit/s)
- 2004 - Introduction of EDGE (~350kbit/s)
- 2005 - Production of 850 000 000 mobile telephones (110 billion dollars business)
- End 2009 - 2 billion mobile phone user (GSM ~ 70%)

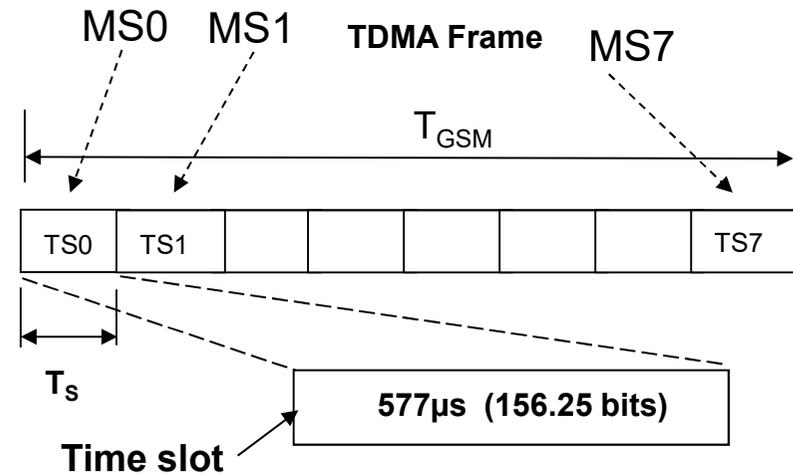
Public system: www.etsi.org www.3gpp.org

Radio transmission technology

Frequency division duplex - FDD

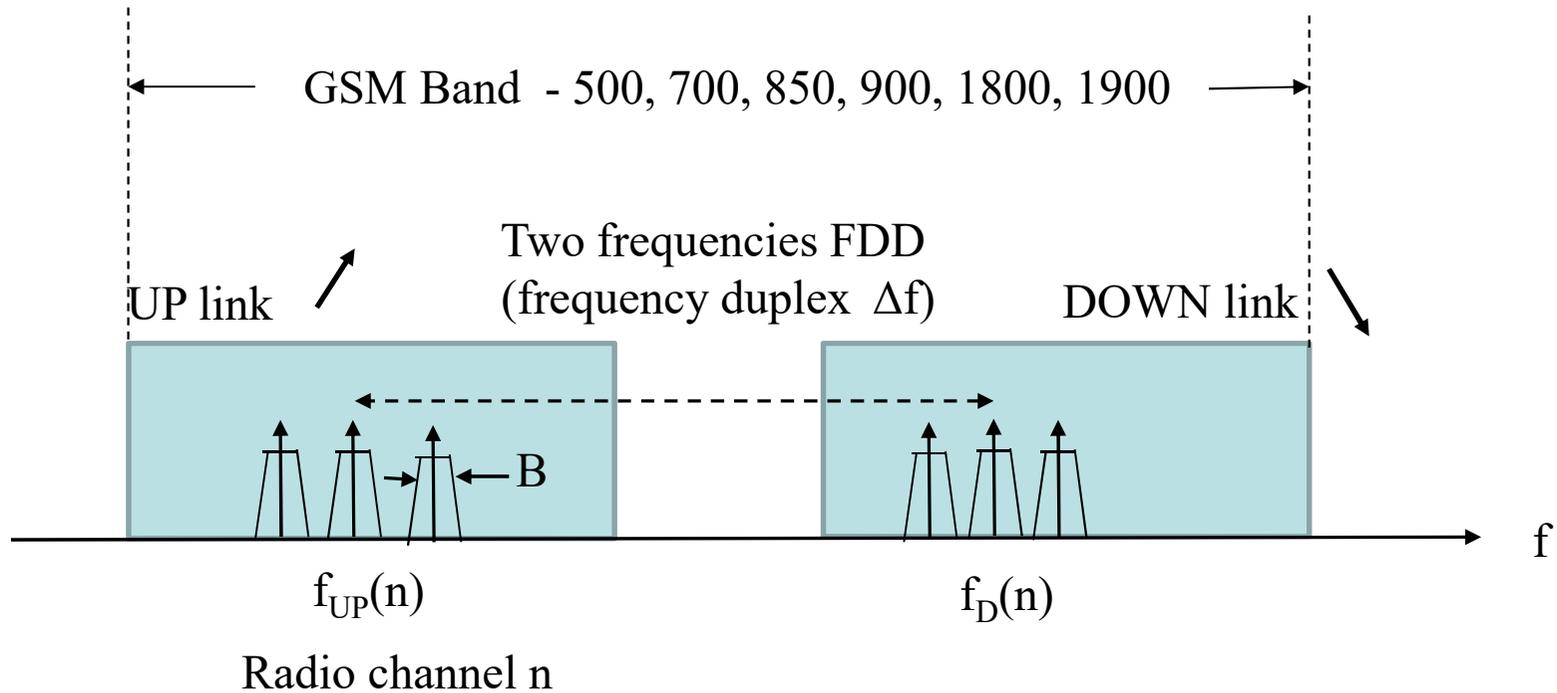


Time division multiplexing - TDMA



GSM Access radio technology – TDMA / FDD

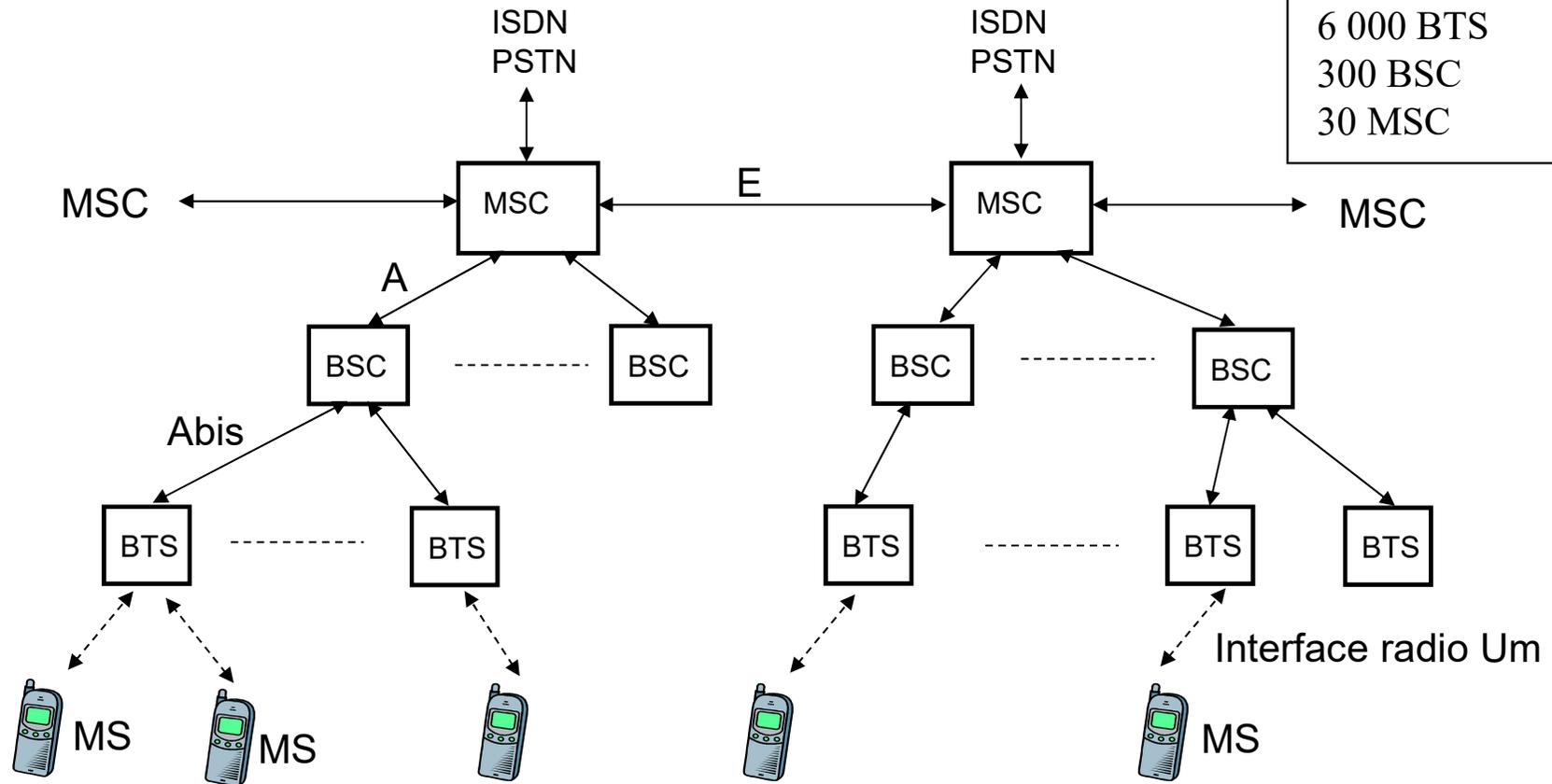
GSM Bands



$n = \text{ARFCN}$

Basic structure of the GSM network (version 1991 – 2G)

France :
 18 000 cell
 6 000 BTS
 300 BSC
 30 MSC

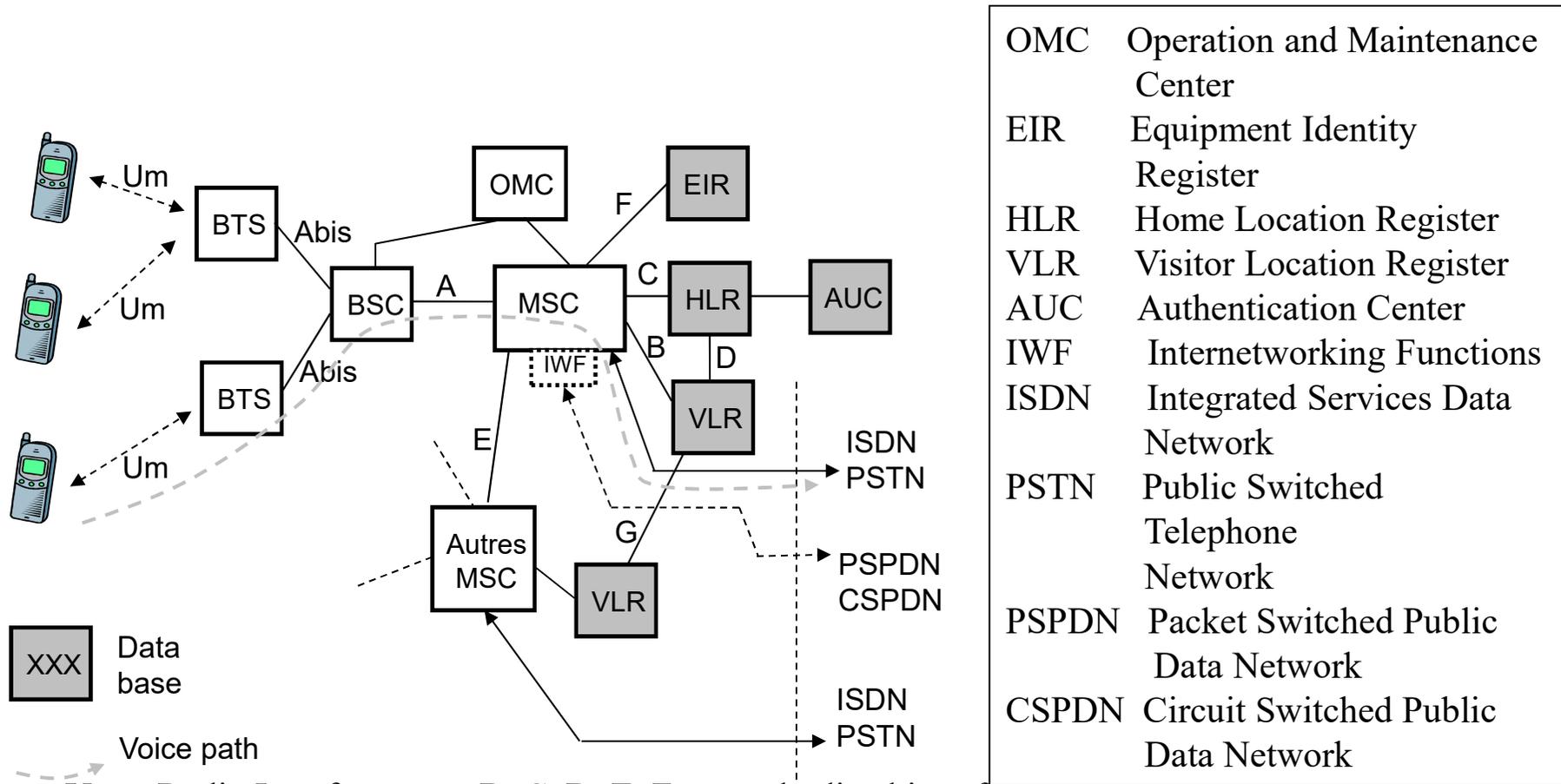


MS – Mobile Station
 BSC – Base Stations Controller
 MSC – Mobile Switching Center

BTS – Base Transceivers Station
 BSS – Base Stations Sub-system

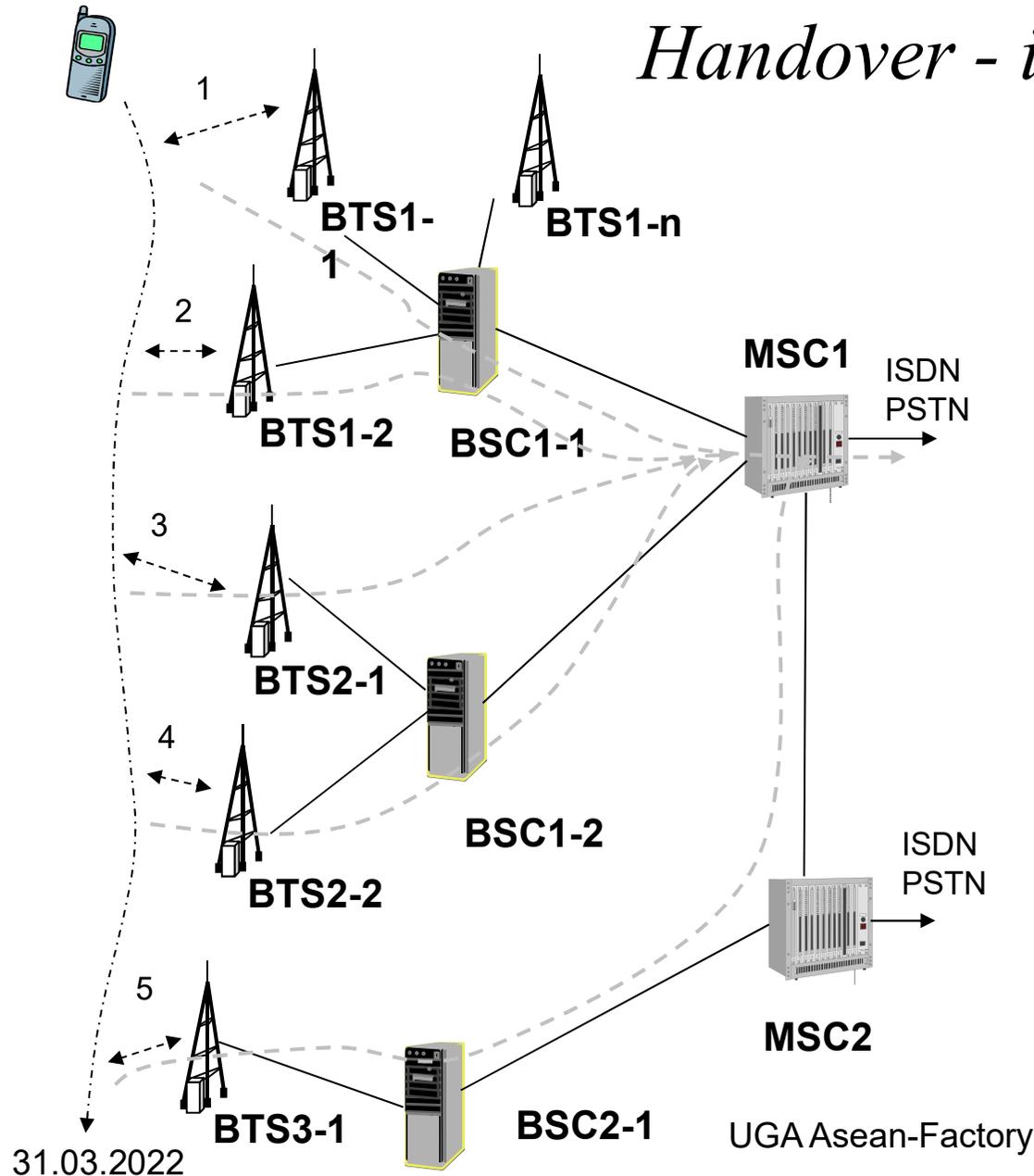
1 BTS : 1- 48 Tx-Rx
 1 BSC : 1- 30 BTS

GSM network and interfaces



Um – Radio Interface B, C, D, E, F – standardized interfaces
 Abis – standardized channel 16 / 64 kbit/s
 A - standardized channel 64 / 2.048 kbit/s

Handover - itinerancy



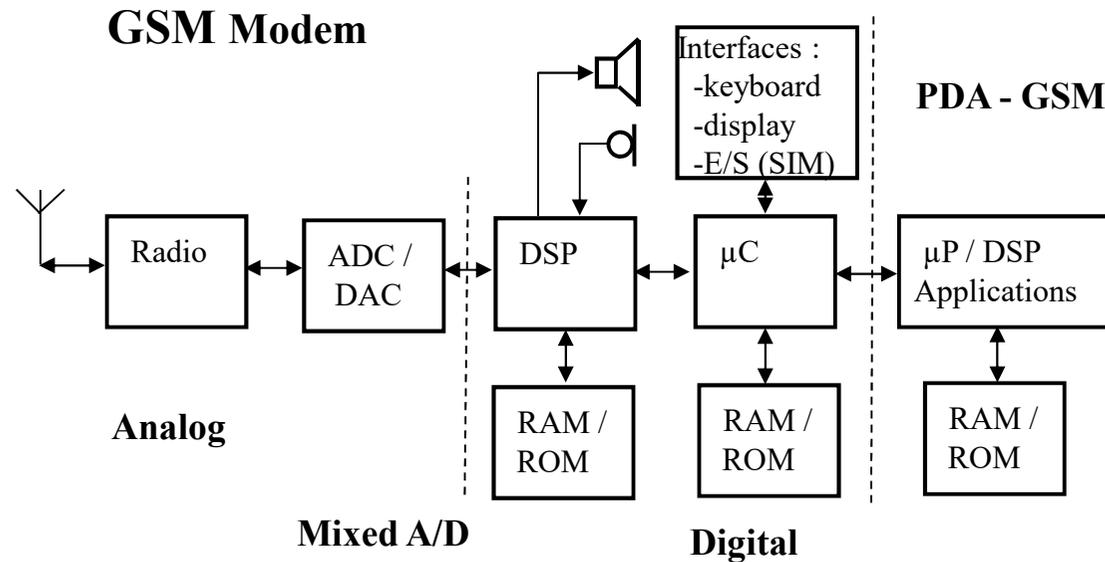
- 1 - 2 Change of cell without change of BSC (*Inter BSC handover*)
- 2 - 3 Change of cells with change of BSC but with the same MSC (*Intra MSC handover*)
- 3- 4 Change of cell without change of BSC
- 4 -5 Change of cells with change of MSC (*Inter MSC handover*)

Rem:

1. If MSC1 and MSC2 belong to different providers: a special subscription is needed to carry out the handover (*Roaming*).

2. The connection with the PSTN is always carried out by the MSC which initiated the communication (*anchor MSC or GMSC – gateway MSC*). 28

GSM Modem



Performances :

DSP : 10 – 40 MIPS, 4-32 k RAM, 16 – 128 k ROM

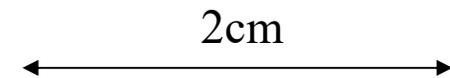
μC : 5 – 10 MIPS, 256k – 1M RAM, 1 – 32 M ROM

Applications: PDA, MP3, VIDEO, GPS

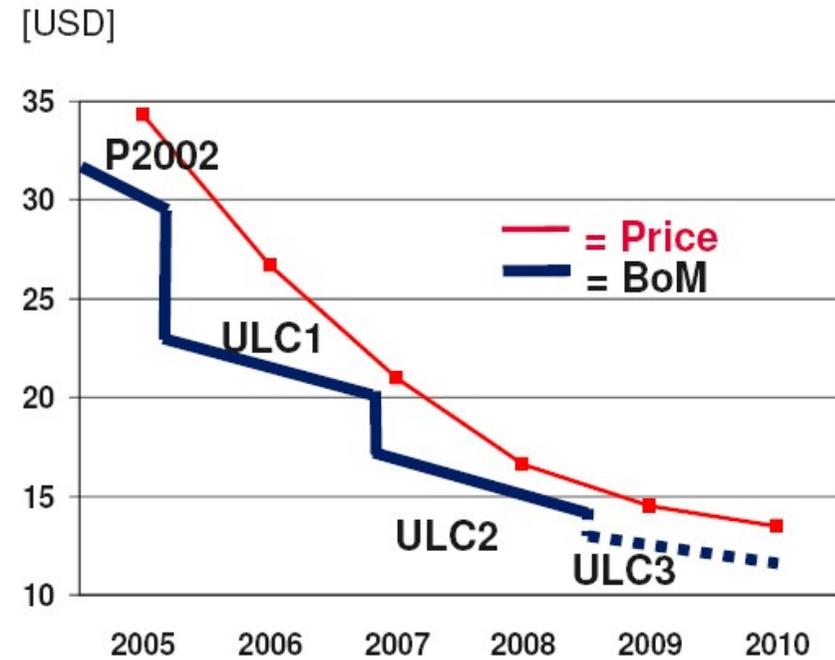
GSM phones: 1998 - 2008



XMM1010
Infineon



GSM – 3 generations



iPhone 5 / 2013

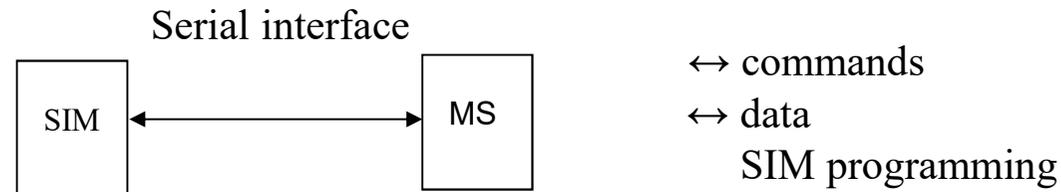


chipworks



chipworks

SIM Card (*Subscriber Identity Module*)



SIM card (Subscriber Identity Module) : User data base / security control.

The data on the card have a file structure:

- Safety data (PINE, PUK, Ki – authentication)
- mandatory data (identifications, IMSI, services, access control, localization, frequencies list of the preferential base stations, list of prohibited BTS, network key Kc, preferential language)
- optional GSM data (directory, SMS, service)
- optional telecom data (last called numbers, annular, additional services)

Protection : PIN (CHV1, CHV2), PUK

GSM Identities

- MSISDN (*Mobile Station ISDN Number*): phone N° of the subscriber (06 xx ... xx)
this number is not used during the GSM communication!
- IMSI (*International Mobile Subscriber Identity*):
permanent identity of the subscriber.
- TMSI (*Temporary Mobile Subscriber Identity*): temporary identity of the user,
this number is allotted by the network.
- MSRN (Mobile Station Roaming Number): temporary code used
during the routing of a call towards a mobile.
- IMEI (*International Mobile Equipment Identity*): serial N° of the mobile.
(read IMEI *#06#)

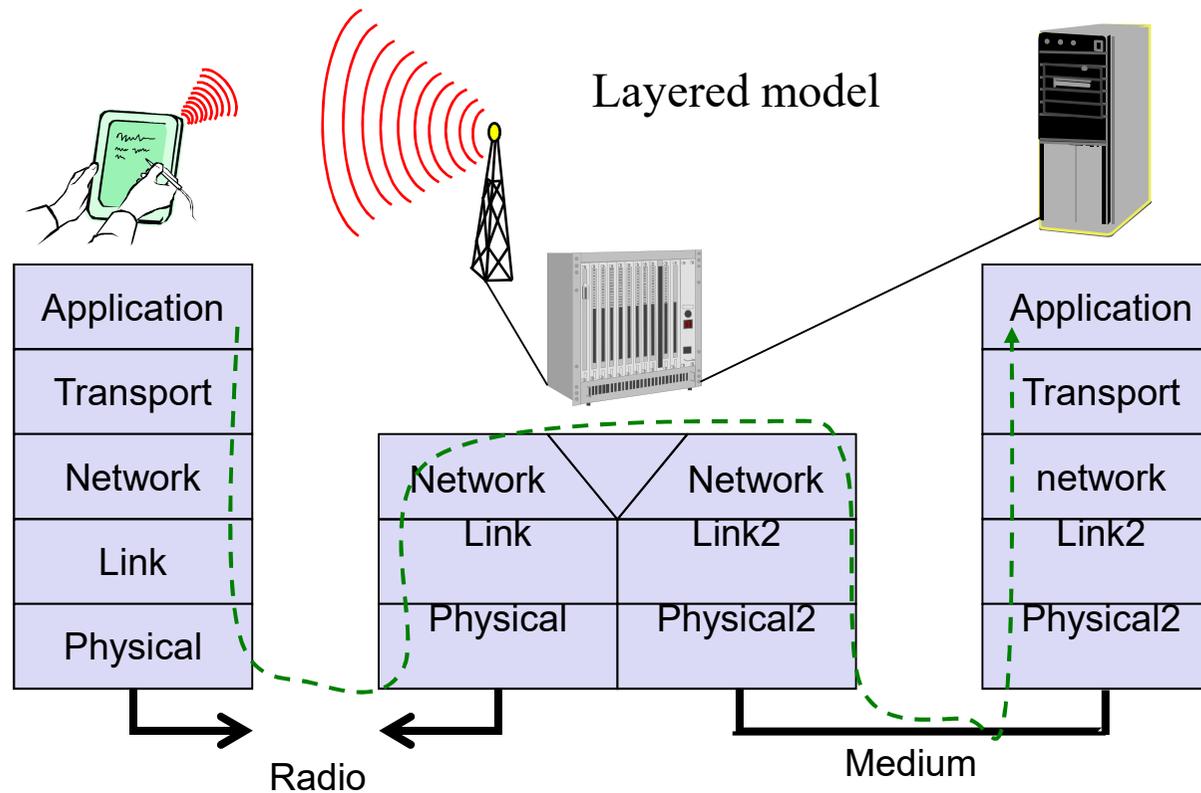
GSM Security

Objectives:

- confidentiality of the subscriber (protect the IMSI)
- authentication of the subscriber
- protection (confidentiality) of the user data
- confidentiality of the signaling (to avoid locating the user)

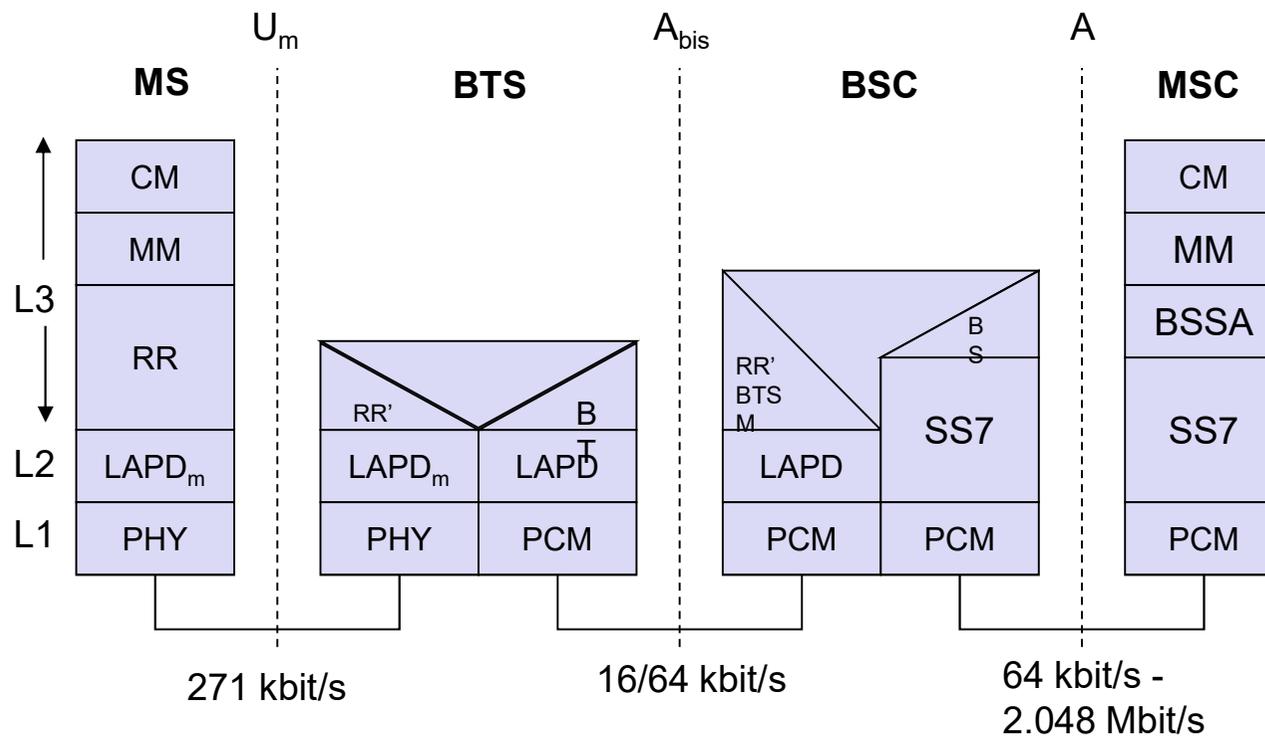
Structure of the GSM protocols

(GSM – the Great Software Monster)



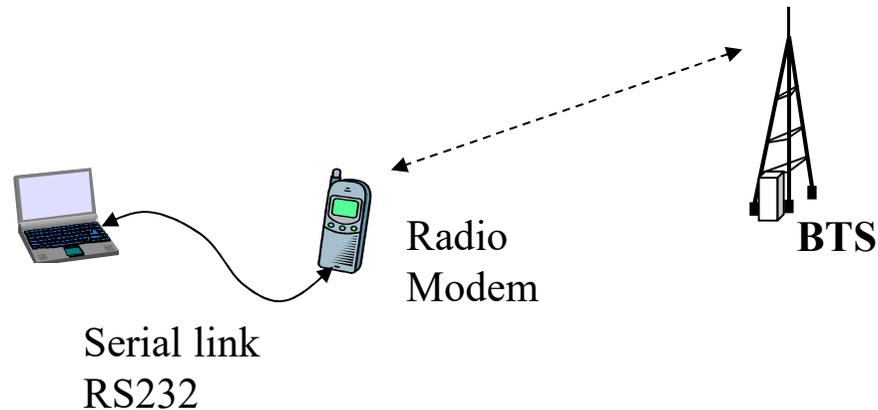
The layer model makes it possible to isolate the different protocols and to define standardized interfaces.

GSM protocols



GSM and Internet

The GSM (Phase1) has a data transfer at the maximum speed of 9600bit/s (14400 bit/s). The commutation mode is by circuit switched data (CS – *Circuit Switched*). The GSM terminal can be used as a radio modem (RLP – *Radio Link Protocol*) . It is possible to make Internet or data transfer (WAP – *Wireless Access Protocol*). However there are three disadvantages in this system:



- the data rate is low
- the communication is in CS mode (the user pay the time he stay on the radio channel independently of the quantity of transmitted information)
- the data flow is symmetrical and cannot be adjustable. In Internet very often one uses a non symmetrical data flow.

Moreover in GSM system Phase 1 the concept of Quality of Service (QoS) does not exist. The GSM infrastructure is not adapted to operate in Internet mode.

GSM-GPRS

In 1998 ETSI decided to introduce the Internet technology into the GSM - Phase 2. To increase the data rate two new technologies were introduced:

- HSCSD (*High Speed Circuit Switched Data*) - technology based on the circuit switching which did not have commercial success and was abandoned
- GPRS (*General Packed Radio Services*) - technology based on the packet switching which was introduced on broad scale in 2002.

Two techniques are used for the increase of the data rate:

a. Multi slot Communication.

In one time slot in GSM it is possible to transfer $D_1 = 2 \times 57 = 114$ bits. On N slots ($N = 1-8$)

it is possible to transmit $N \times 114$ bits. $D_{\max} = (8 \times 114 \times 1000) / 4.165 = 197\ 616 \text{ bit/s}$

The 114 bits are not only “user” bits. Among these bits there are data bit and protection bits.

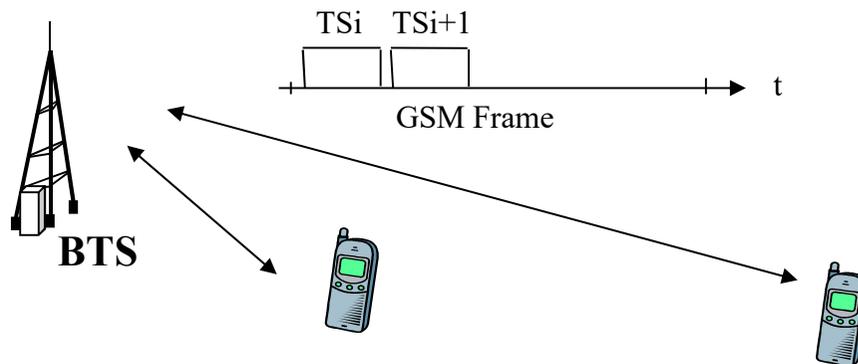
b. Protection control according to the quality of the channel.

If the quality of the transmission is good one can decrease protection against the errors and transmit more “user” bits by slot. This occurs for example when the mobile is close to the BTS. By adapting the type of convolutional coding to the quality of radio channel it is possible to gain in data rate.

This is done by the introduction of different Coding Scheme (CS).

GPRS

1. Multi slot transmission



2. Code control

- S/N low
More protection (D low)
- S/N good
Less protection (D higher)

Classe	Slot en réception	Slot en émission	N° total de slot
1	1	1	2
2	2	1	3
3	2	2	4
5	2	2	4
8	4	1	5
10	4	2	6
12	4	4	8

Codage	1 slot	2 slot	3 slot	4 slot	5 slot	6 slot	7 slot	8 slot
CS-1	9.05	18.2	27.15	36.2	45.25	54.3	63.35	72.4
CS-2	13.4	26.8	40.2	53.6	67	80.4	93.8	107.2
CS-3	15.6	31.2	46.8	62.4	78	93.6	109.2	124.8
CS-4	21.4	42.8	64.2	85.6	107	128.4	149.8	171.2

Maximum data rate in GPRS : 171.2 kbit/s

Real GSM-GPRS data rate \sim 100kbit/s. Most of the portable are class 8 ou 10. It is possible to adjust the data flow according to the application by using a variable number of slots. It is possible to adjust the ratio of the data flow in uplink and downlink (for example 4 slots down and 1 slot up).

Schéma de codage	Débit utilisateur (kbit/s) (par time-slot)
CS-1	9.05
CS-2	13.4
CS-3	15.6
CS-4	21.4

GPRS services

PS - Packet Switched Data communication

In this mode a “virtual” connection is established between MS and the network. The parameters of the communication channel (radio channel) are negotiated and the network books the necessary resources. However the radio channel is not established physically. As soon as there are sufficient data to be transmitted (accumulation of a packet) the channel is established, the data are transferred and the channel is released. Thus the radio resources are used only where there is a need for that.

- Optimization of the use of the radio interface and the network
- Only the quantity of transmitted information is paid (and not the connection time)!

Quality of the service (QoS)

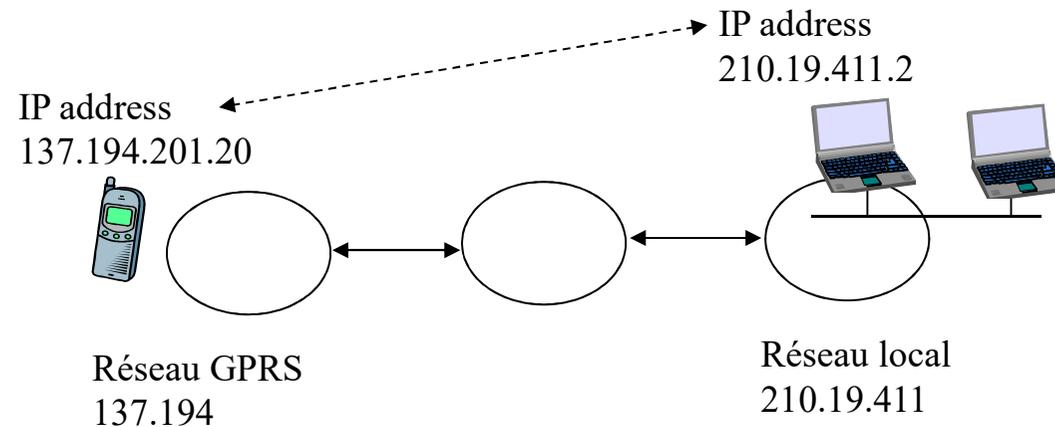
The Quality of Service (QoS) comprises four parameters:

- Data rate (kbit/s)
- Delay Time (maximum delay between transmission and reception of the data)
- Reliability (acceptable maximum errors rate)
- Precedence (the packages are delivered in the order of transmission)

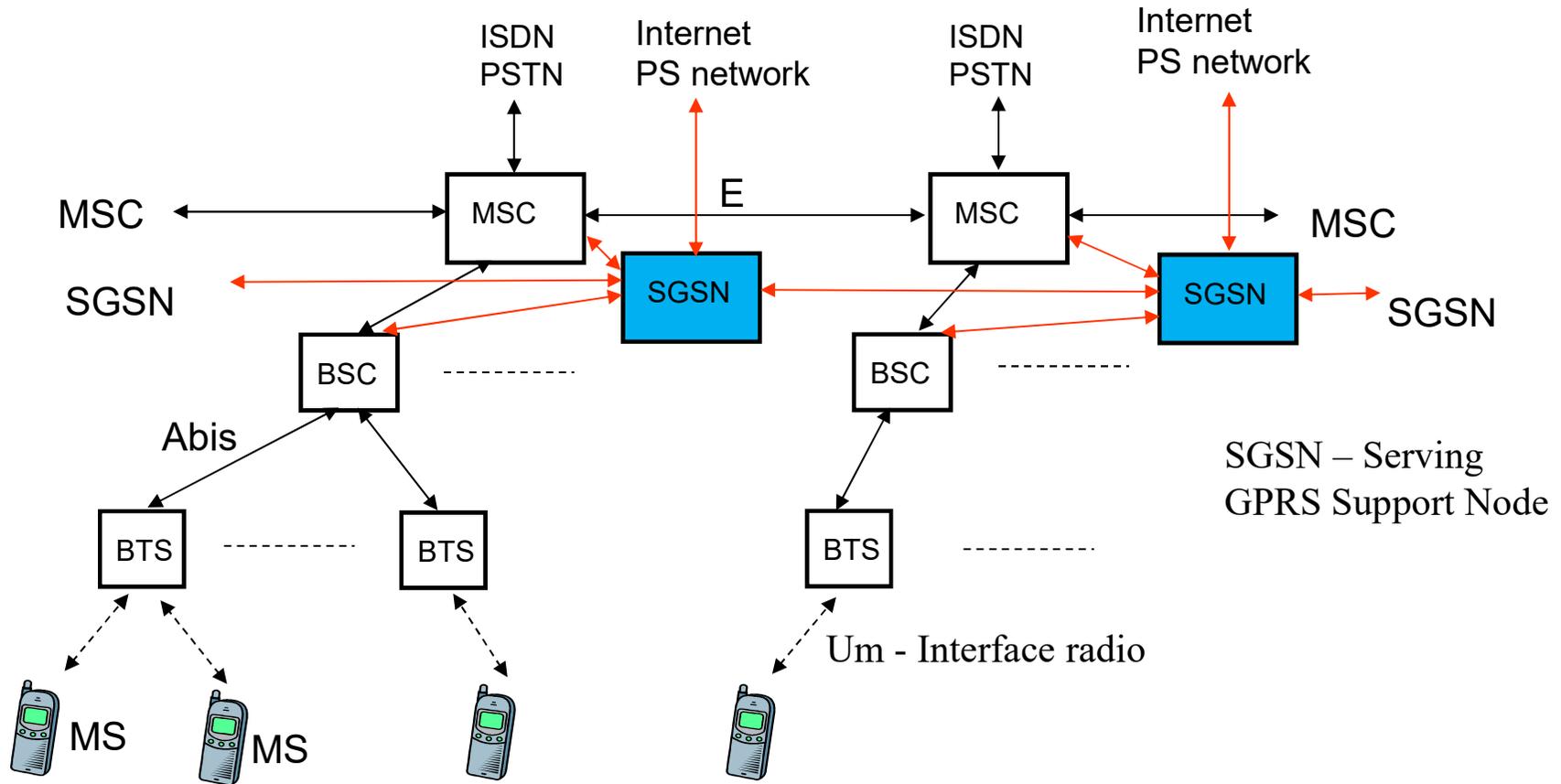
Each portable, according to the application which it will carry out and of the subscription which the user has, can negotiate the QoS during its connection to the GPRS network.

GPRS – model of operation

A GSM MS in GPRS mode becomes a terminal (or modem) completely compatible with the Internet infrastructures and protocols. It can have an IP address and communicate with any type of networks.

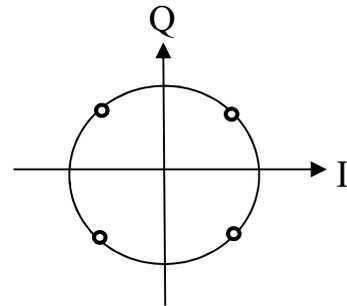


GPRS – network architecture

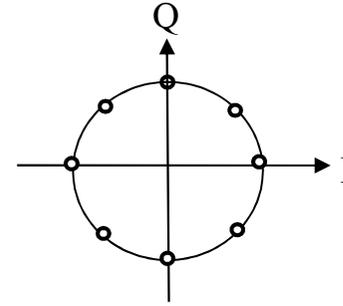


EDGE (384kbit/s)

In 2001, with the aim of further increasing the data rate in GSM a new standard - the EDGE (*Enhanced Data splreens for Global Evolution*) was introduced. This standard is based on a new radio layer (physical layer) specified by the international organization of telecommunications (ITU). EDGE uses a new phase modulation - PSK-8. This modulation makes it possible to transmit 3 bits per symbol.



GSM : 2 bits/symbol



EDGE : 3 bits/symbol

Advantages:

- higher data rate

Disadvantages:

- the modulation is more sensitive to the noise
- the envelope of the modulated signal is not constant: the power amplifiers are more complicated (and more expensive).
- the convolutional decoding is more complex.

UMTS

Objectives of UMTS (*Universal Mobile Telecommunications System*)

- to replace the GSM by ensuring a continuity and improvement of the existing services (voice, SMS, data)
- to propose a broad range of new services (music, video, TV)
- to ensure high data rates under various conditions of radio propagation and particularly in urban and indoor environments
- to ensure the convergence “telephony – data” towards the IP network
- maximal re-use of the GSM infrastructure.

Open system: spécifications : www.3gpp.org, commercial exploitation : 2004

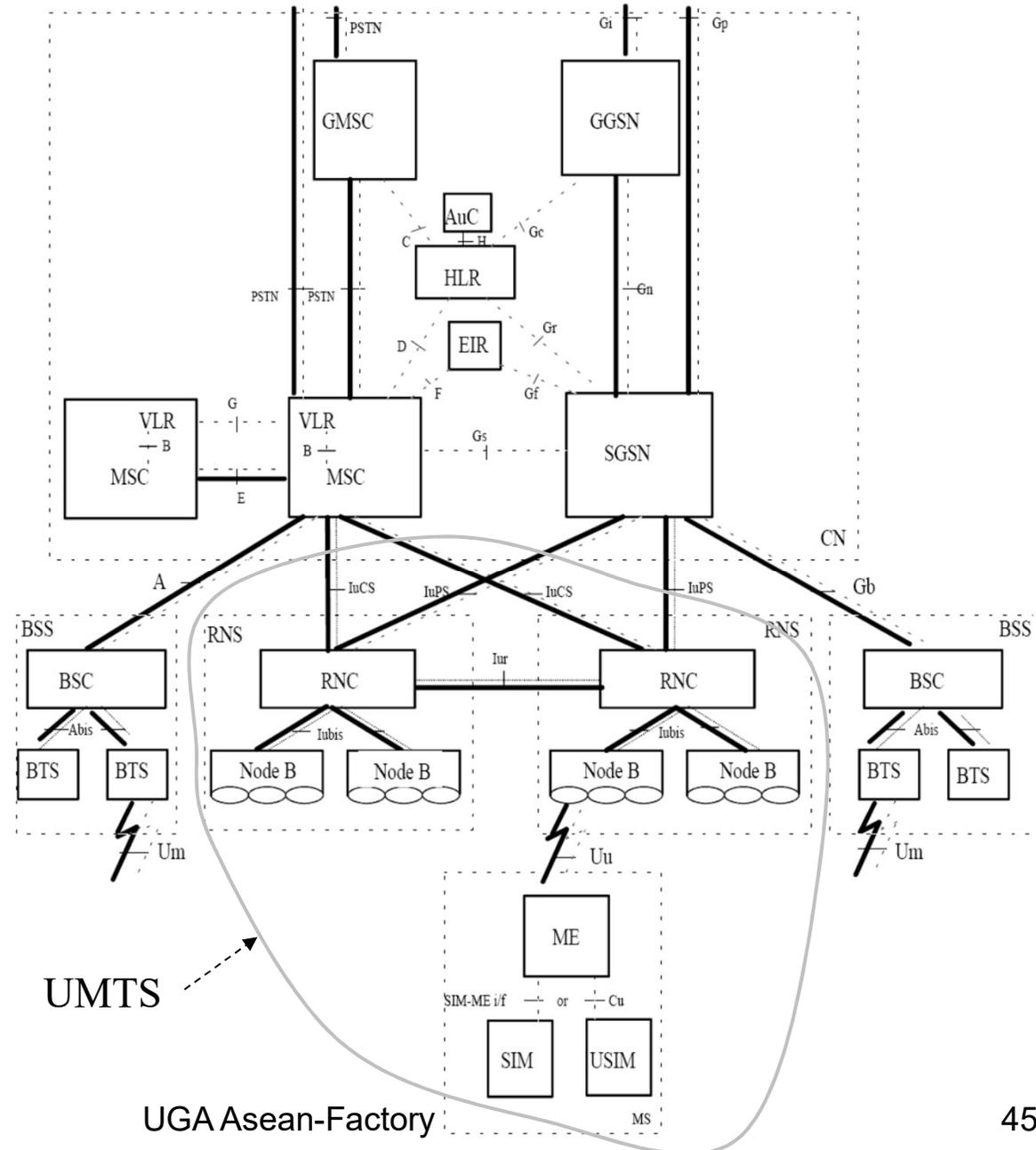
Radio technology: Direct sequence spread spectrum (DS-SS) with Code Division Multiple Access (CDMA).

Data rates :

min. 144 kbit/s rural (384 kbit/s)
min. 384 kbit/s semi urbain (512 kbit/s)
up to 2 Mbit/s urbain

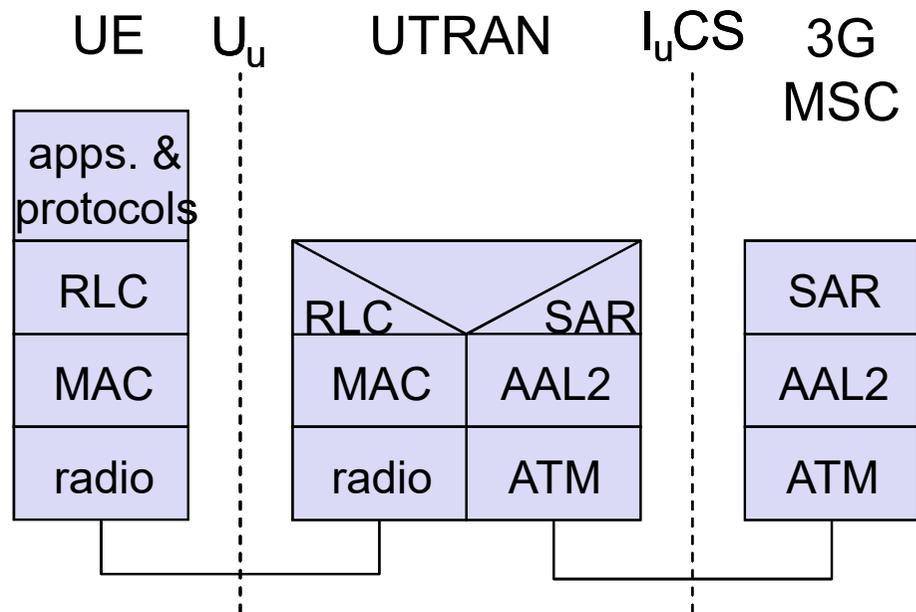
Rem. HSDPA (*High Speed Downlink Packet Access*) - 2004:

UMTS / GSM (reuse of the GSM / GPRS core network)



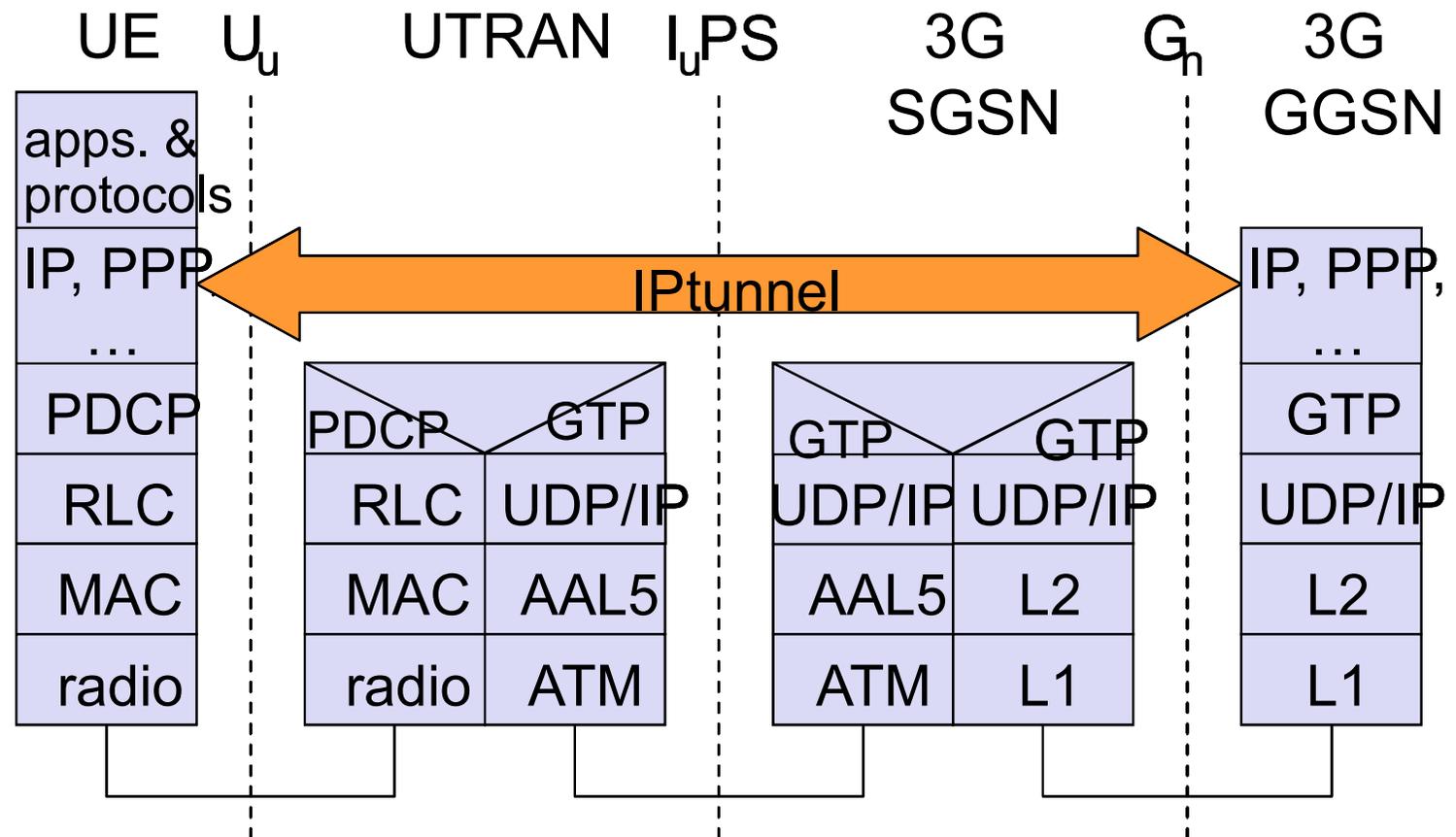
Protocols: CS mode

Circuit switched (*CS data*)

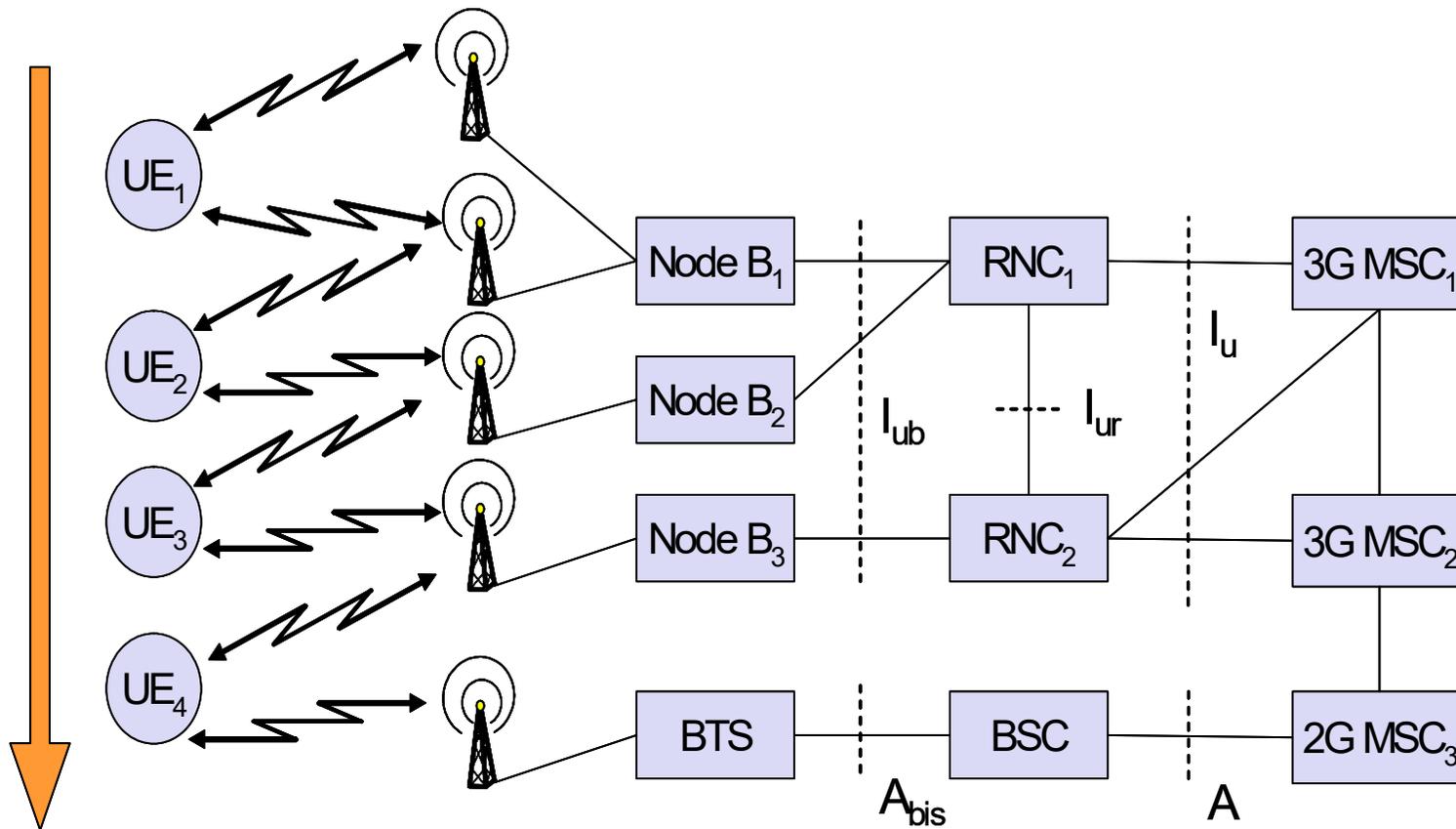


Protocols : PS mode

Packet switched mode(*PS data*)



Inter system handover : GSM ↔ UMTS



UMTS Evolution

	UMTS WCDMA	HSPA HSPDA/HSUPA	HSPA+	4G LTE
Data rate (Down link) Max :	384 kbits/s	14 Mbits/s	28 Mbits/s	100 Mbits/s
Data rate (Up link) Max :	28 kbits/s	5.7 Mbits/s	11 Mbits/s	50 Mbits/s
Mean latency	150 ms	100 ms	50 ms	10ms (Control applications)
Access Mode	CDMA	CDMA	CDMA	OFDMA/SC-FDMA

LTE – 4G

But de LTE (*Long Terme Evolution*)

- satisfaire le besoin de données mobiles (Internet mobile)
- proposer du haut débit et accès direct aux réseaux IP
- PS data
- diminuer le prix de l'infrastructure (Réutilisation des réseaux IP)
- utilisation de petites et très petites cellules (*femto cell*)
- développement du système : 2008 – 2012

(spécifications : www.3gpp.org)

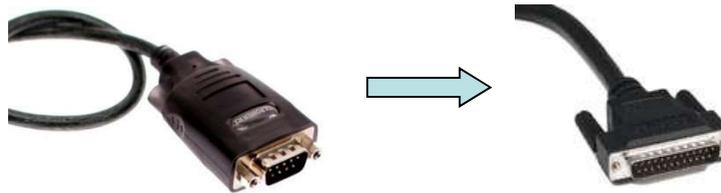
introduction commerciale du service : 2015

Technologie radio : OFDMA (station de base), SC-FDMA (mobile) ,
utilisation d'antennes multiples MIMO, technique de multiplexage : FDD, TDD,
Contrôle flexible de la bande passante radio (1,4 – 20 MHz)

Débit théorique: Up 50 Mbit/s, Down 100 Mbit/s

High Data Rate Radio Communications

- Techniques de diminution (élimination) de l'ISI:
 - égalisation GSM
 - étalement du spectre DS-SS UMTS
 - allongement artificiel de la durée du bit – OFDM LTE
- OFDM (Orthogonal Frequency Division Multiplexing) : Idée de base - transformer **les bits en série rapides en bits (ou symboles) lents en parallèle** de durée plus grande que l'étalement maximal du canal de propagation.



- L'OFDM a été développée dans les années 60. Actuellement la modulation est utilisée en :
 - Radio numérique : DAB
 - Télévision numérique: TNT / DVBT
 - Télévision satellite
 - WiFi (801.11a/g/n), WiMax (802.16d)

Minuaturization

Computers



Mainframe



Mini-computer



Personal - computer

Cellular Base Stations



Macrocell



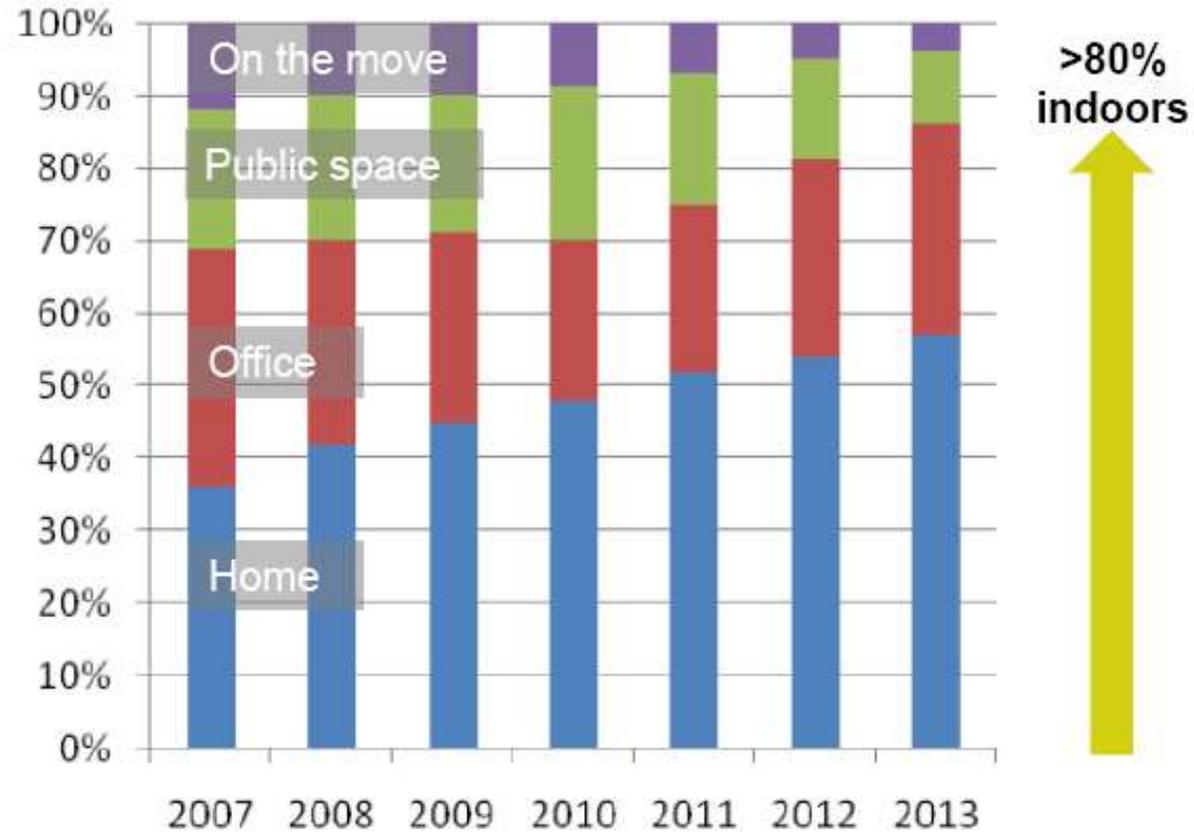
Picocell



Femtocell

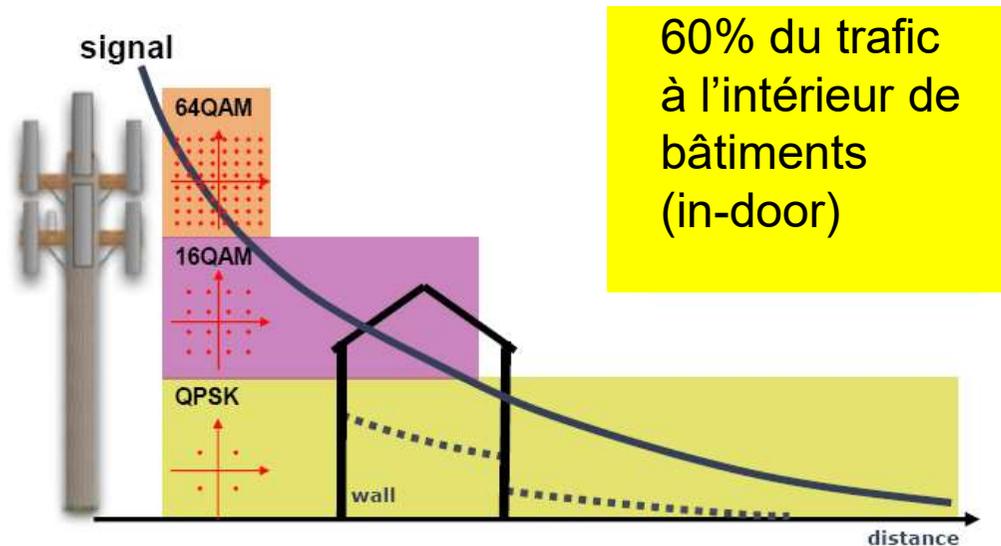
Nano-, pico-, and femto-cell : WCDMA / UMTS et LTE

Traffic Evolution



Source: VisionGain

Why do we need small cells for LTE?

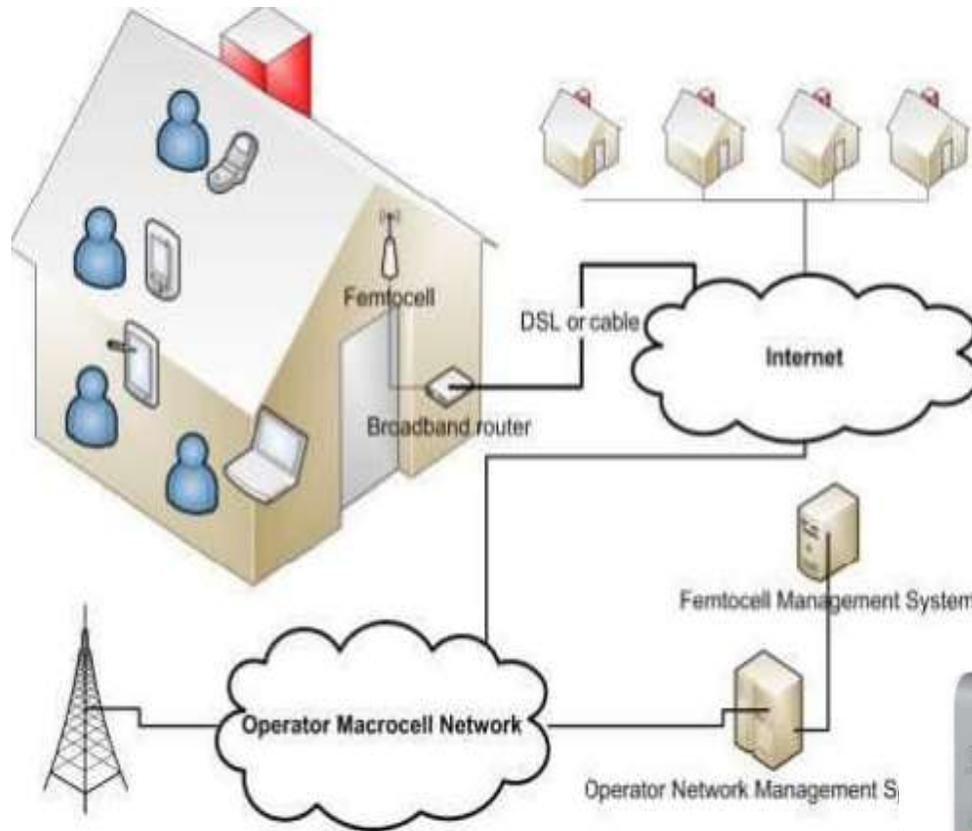


- Modulation nQAM ($n = 2 - 6$) du LTE – très sensible au bruit
Augmenter le rapport Signal/Bruit :
 - augmenter la puissance (impossible)
 - diminuer la distance (petites cellules)

HeNB (Home evolved NodeB)

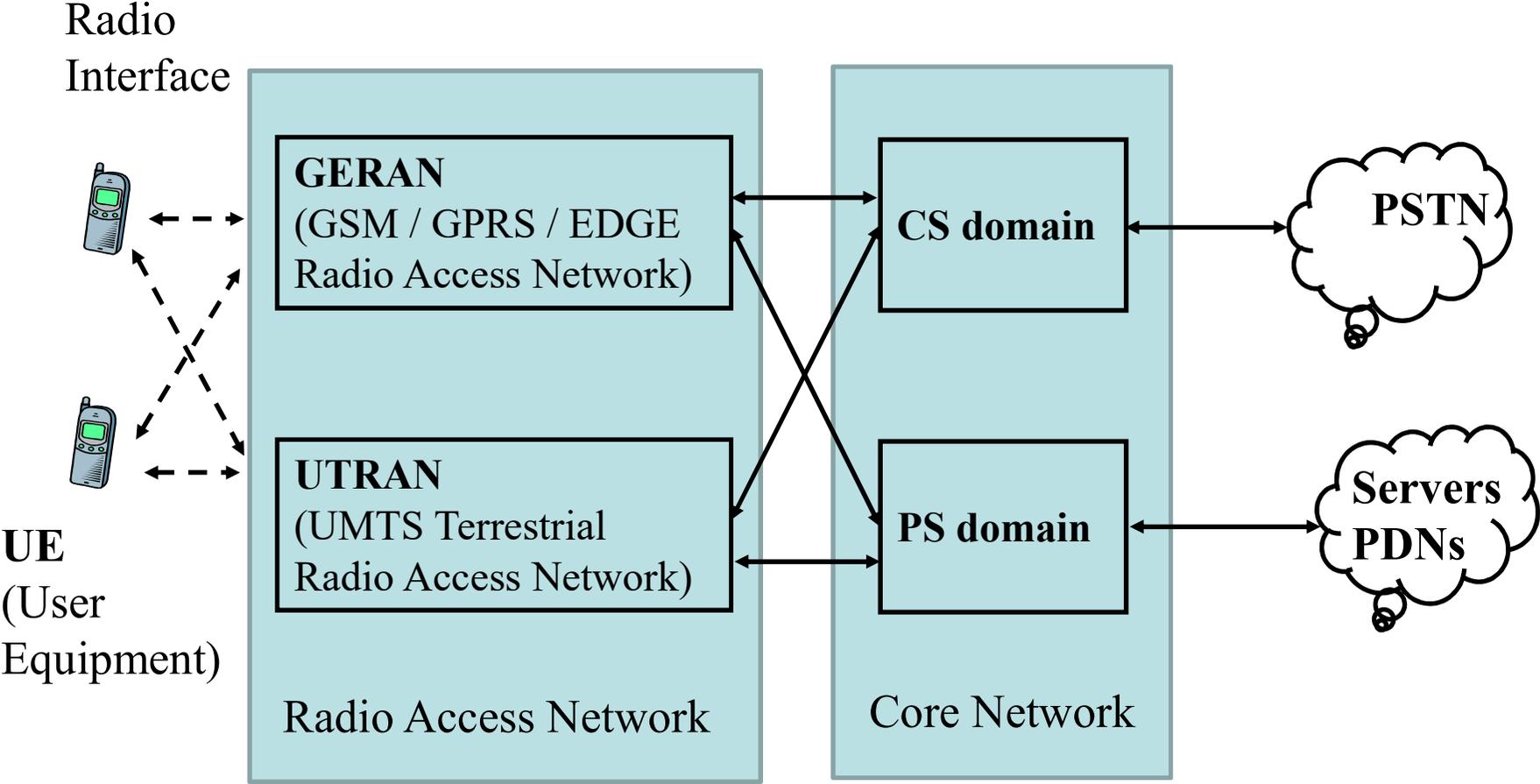
Femtocell

- Point d'accès domestique
- Faible puissance
- Utilise un spectre licencié (géré par l'opérateur)
- Couverture: quelques dizaines de mètres
- Haute capacité de données
- Connexion à l'infrastructure opérateur par Internet
- Faible prix (~20 euros)

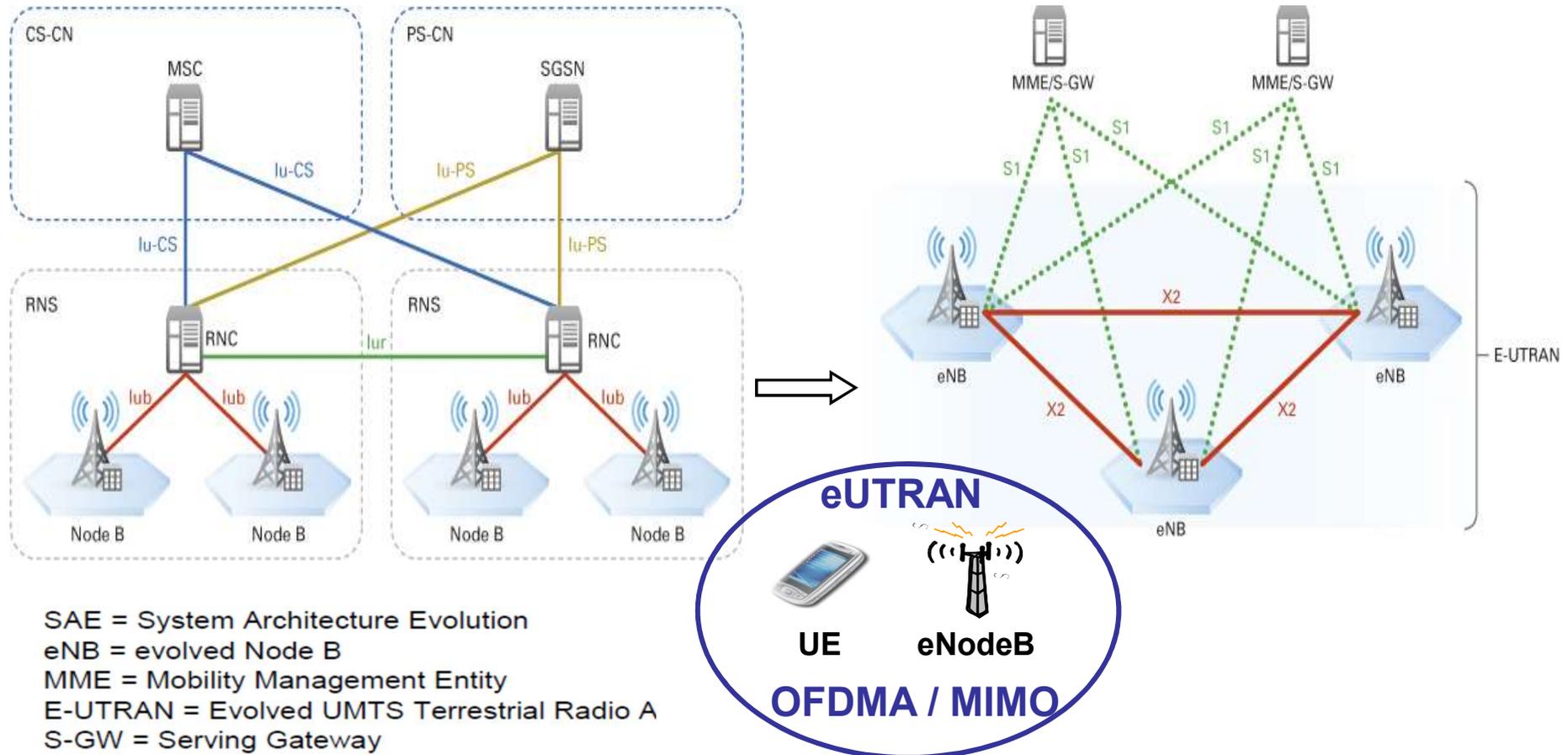


WCDMA femto BTS
8 UE
HSDPA – 15Mbit/s
HSUPA – 5.7Mbit/s
Couverture radio 20m

2G – 3G Architecture

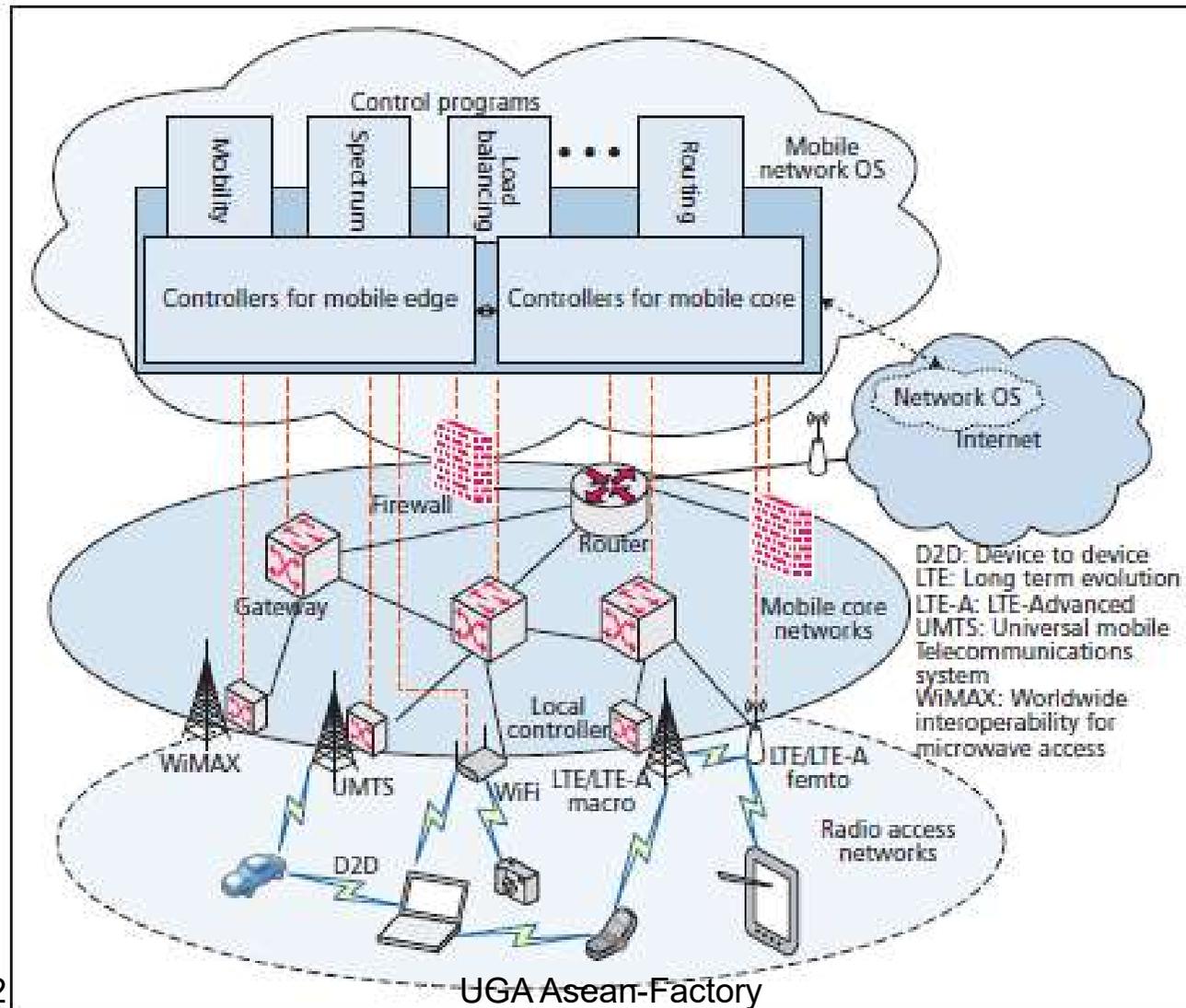


LTE Network Architecture (all IP network)

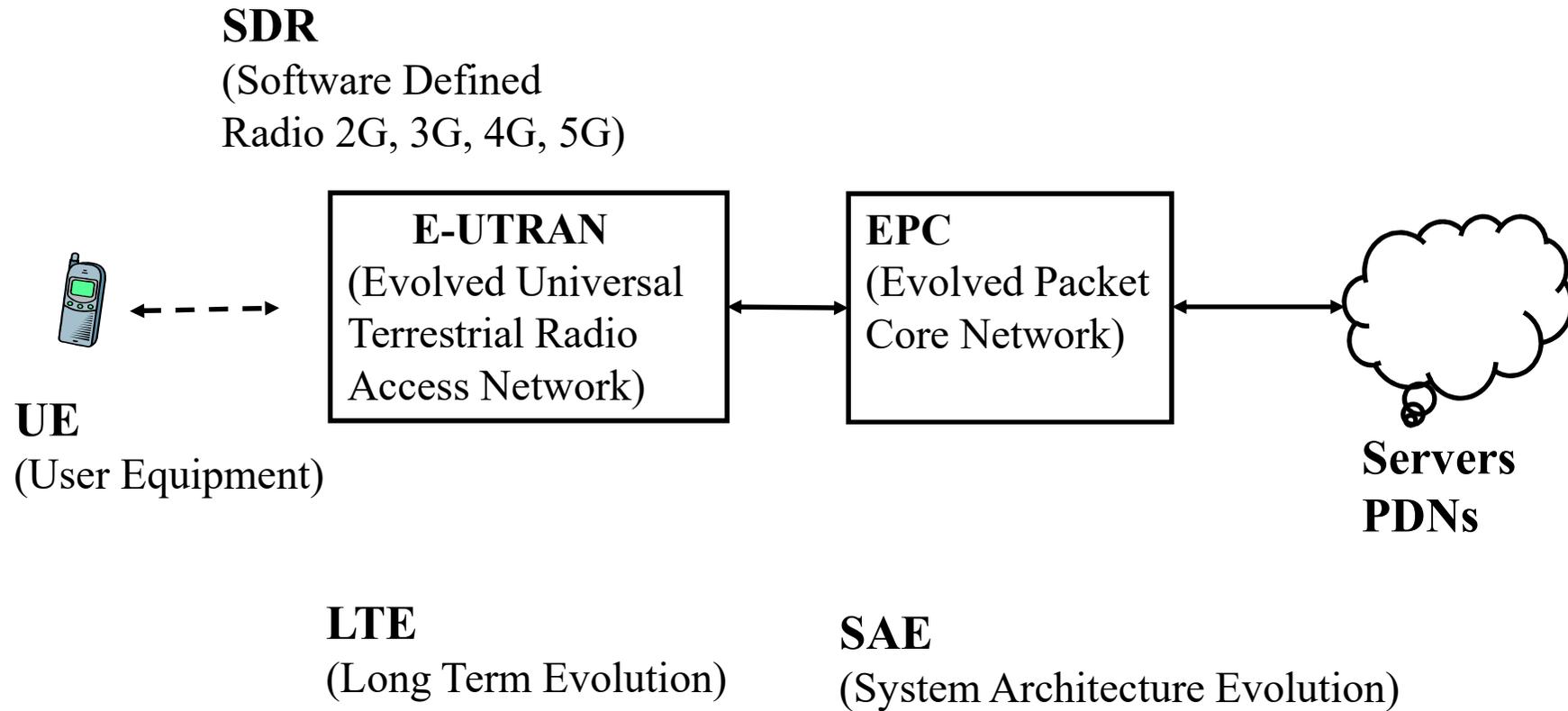


- Les composants de l'infrastructure communiquent entre eux à tous les niveaux
- Les interfaces de communications utilisent le protocole Internet (IP)

SDN – Software Defined Networks (Virtualization)



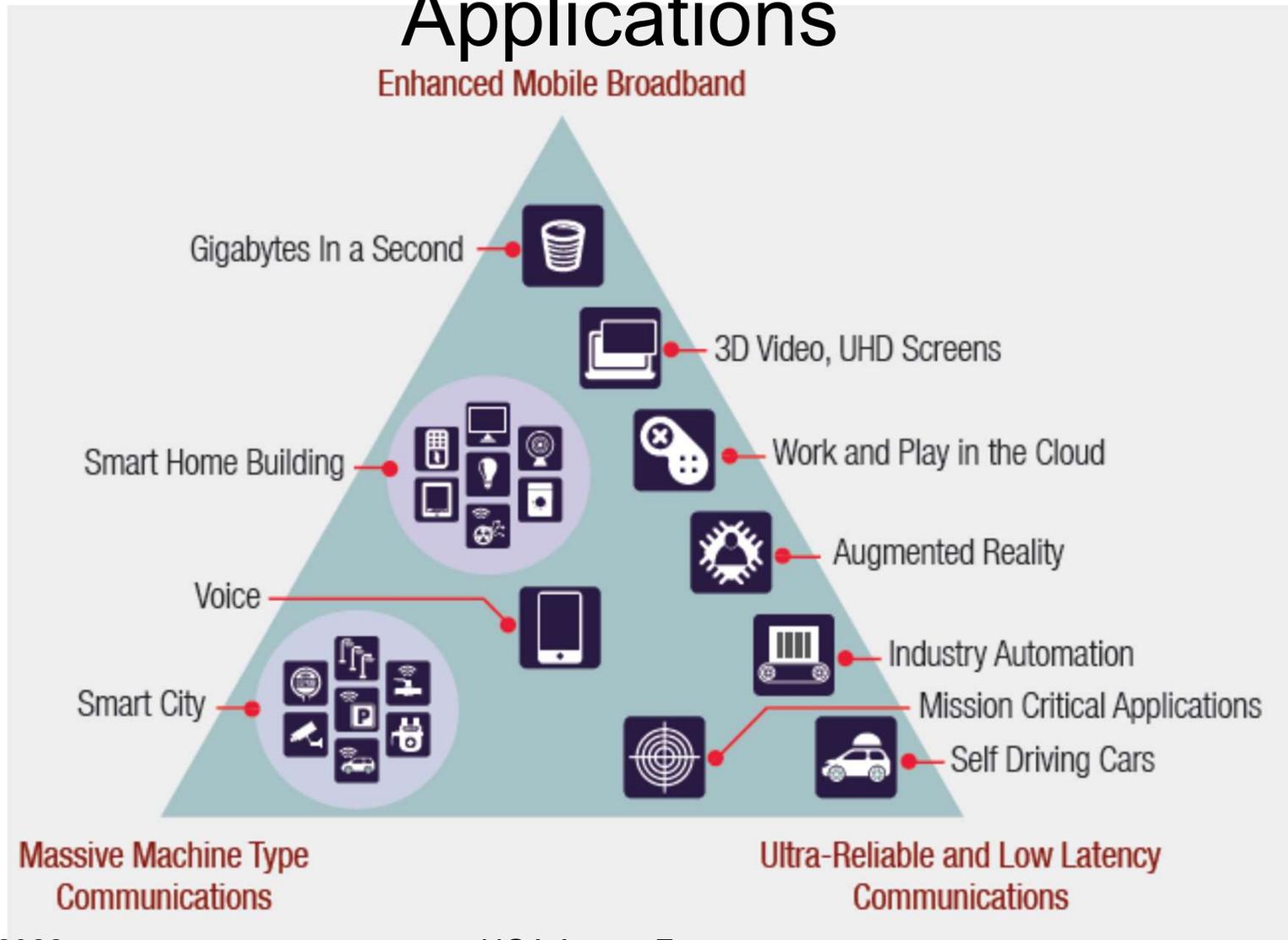
LTE / SAE



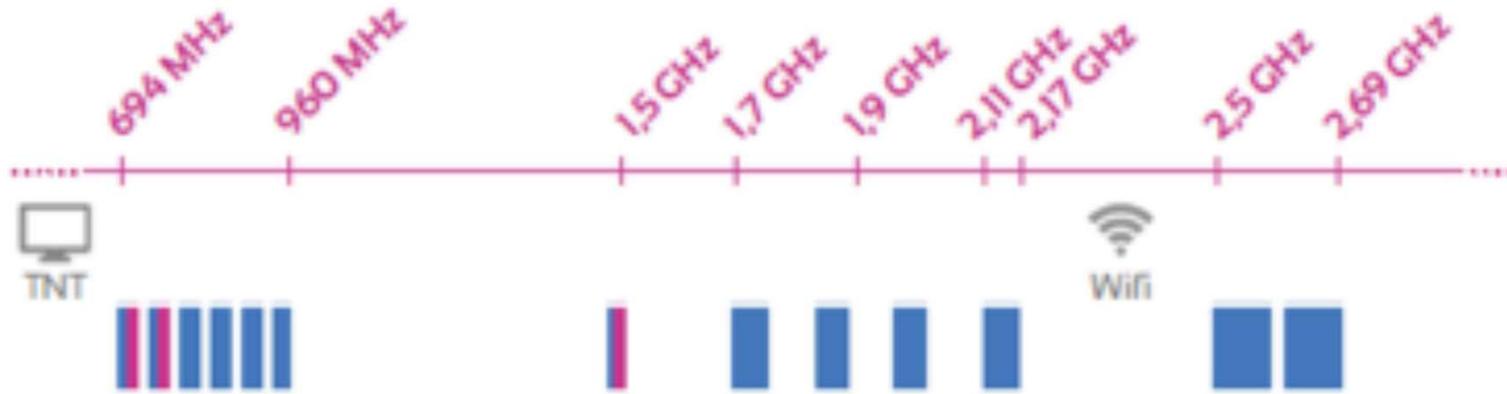
2G – 3G – 4G

	2G - GSM	3G - UMTS	4G - LTE
Bandes de Fréquences [MHz]	880 – 960 1710 - 1880	1885 – 2015 2110 – 2200 + GSM 900	2500 – 2600 + UMTS 700 – 800 (TV)
Puissance d'émission max. du terminal [W]	2	0.25	0.125
Duplex	FDD	FDD et TDD	FDD et TDD
Accès multiple	FDMA/TDMA	CDMA	↓ OFDMA, ↑ SC-FDMA
Modulation	GMSK	PSK, QPSK, n-QAM	PSK, n-QAM
Services	Voix, SMS, données (14.4 kbit/s)	Voix / données (2 Mbit/s)	Données, VoIP ↓ 100 Mbit/s ↑ 50 Mbit/s
Type de commutation	CS (par circuits)	CS / CP (par paquets)	CP
Evolutions	<ul style="list-style-type: none"> • GPRS : CP, 171,2 kbit/s • EDGE : 8-QPSK, 384,4 kbit/s 	<ul style="list-style-type: none"> • HSPA : ↑ 5,76 Mbit/s, ↓ 14,4 Mbit/s • HSPA+ : ↑↓ 21 Mbit/s • MIMO 	<ul style="list-style-type: none"> MIMO ↓ 300 Mbit/s ↑ 75 Mbit/s
Internet of Things IoT			
Nouvelles normes 4G: NB-IoT, LTE-M (M2M) 2G: EC-GSM 3G : non!			

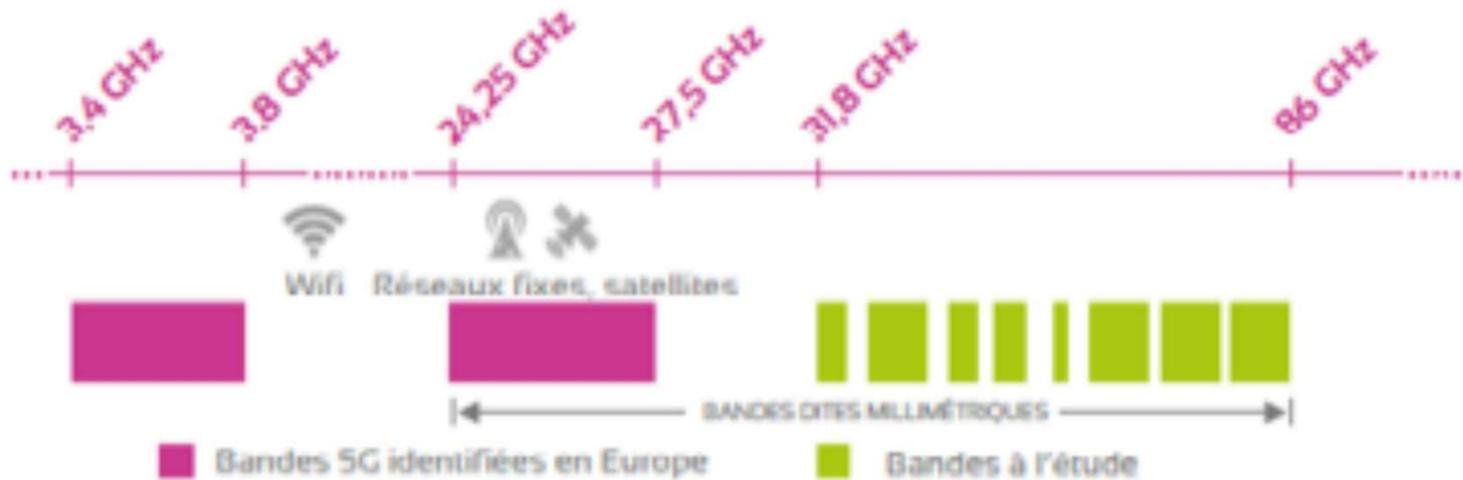
5G – Professional Quality Link & Applications



New Frequency Bands



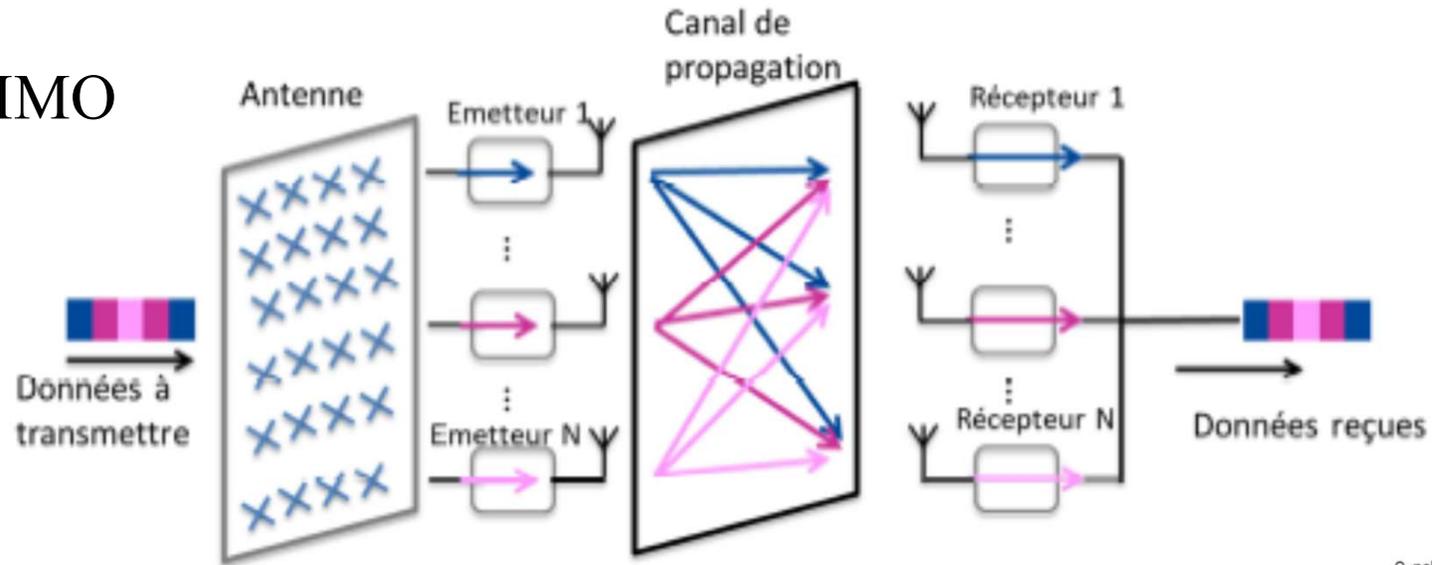
Low" bands: good indoor propagation



High" bands: high data capacity, limited indoor propagation

High Data Rate Radio Technologies

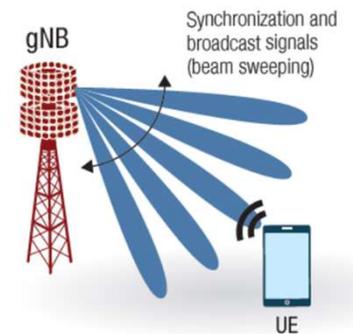
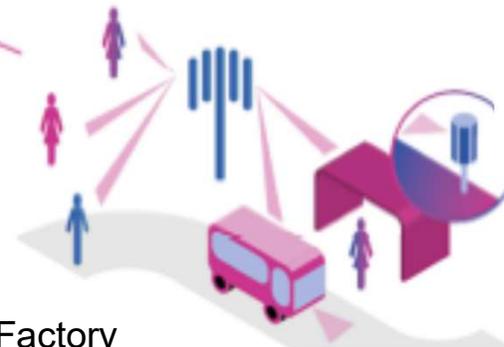
1. MIMO



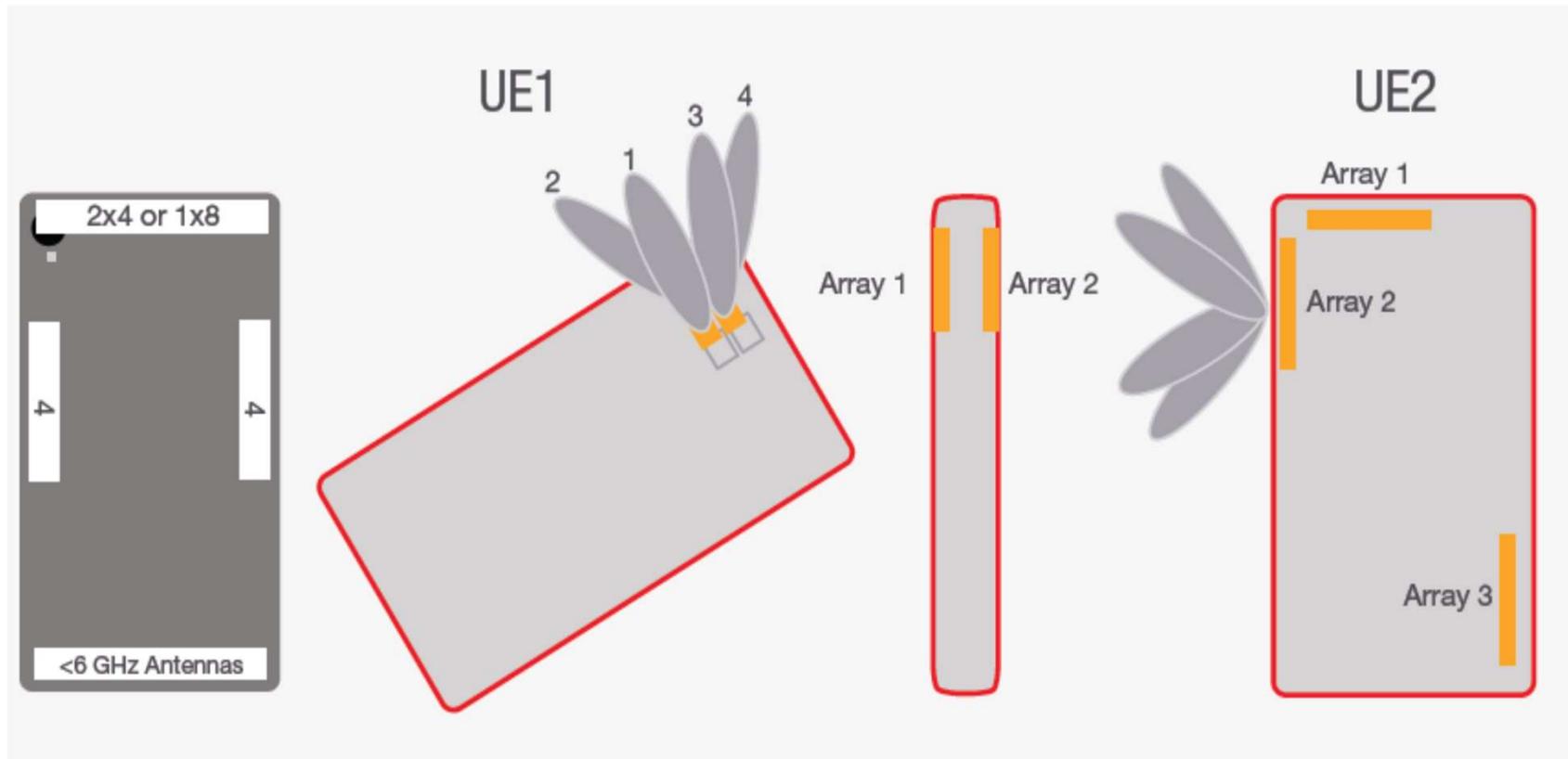
2. RF Beam Steering



ANTENNES 5G
Gain typique 24 dBi



Multiple Antenna (Phased Array) UE

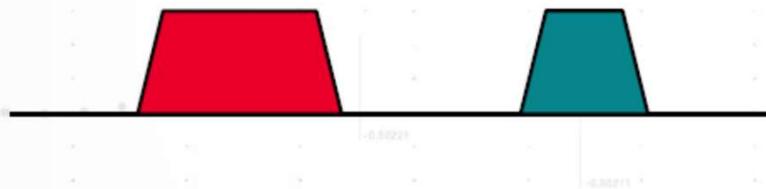


Spectrum management (Band and Carrier frequency aggregation)

- Component Carriers may be in the same band and adjacent



- Or they could be in the same band, non-contiguous



- Or in different bands

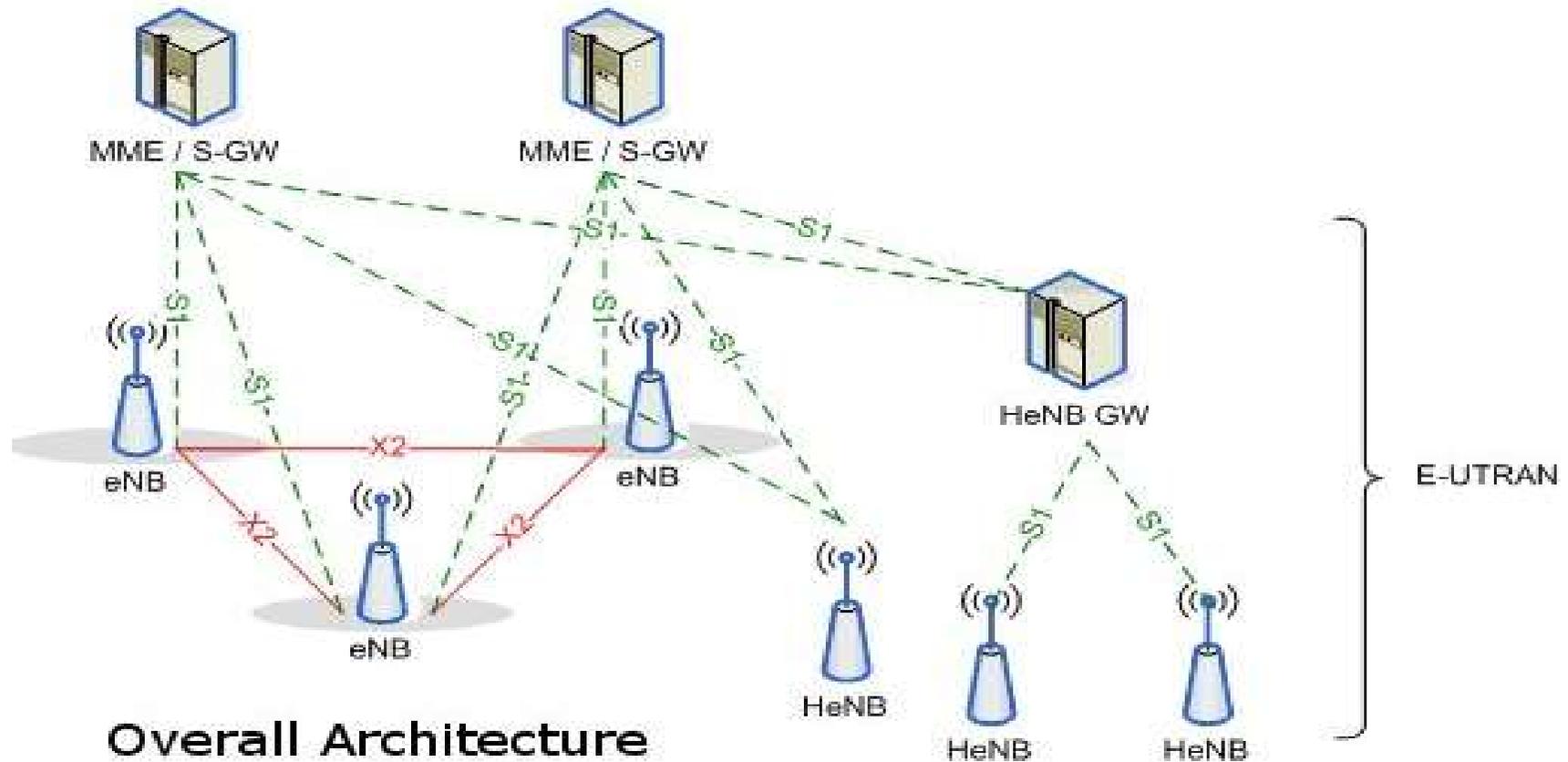


Band A – sub-6 GHz

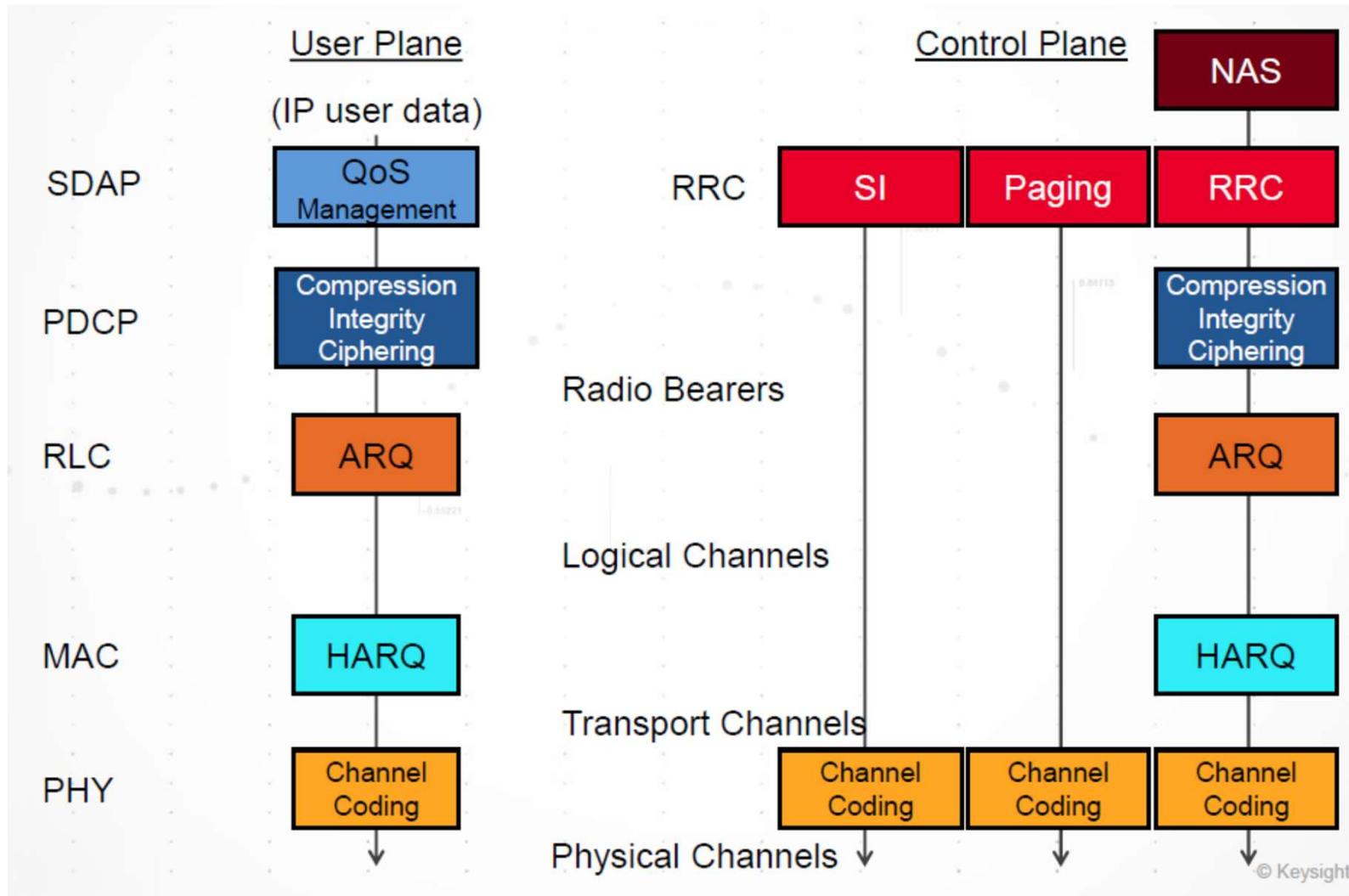


Band B – mm-wave (28GHz)

NG RAN Architecture



Protocoles

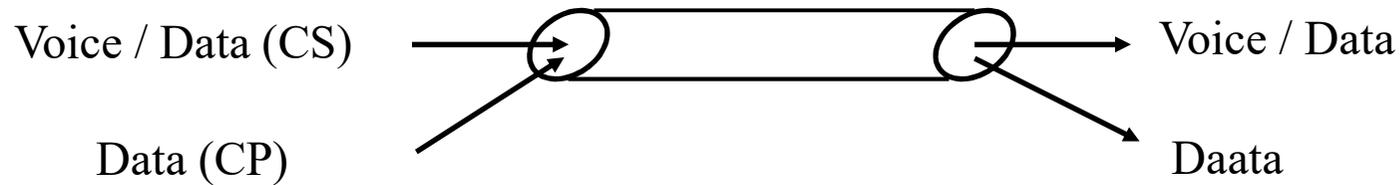


2G – 3G – 4G – 5G

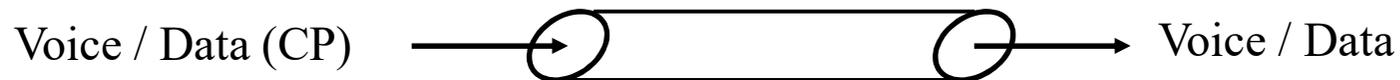
2G GSM



3G UMTS



4G LTE

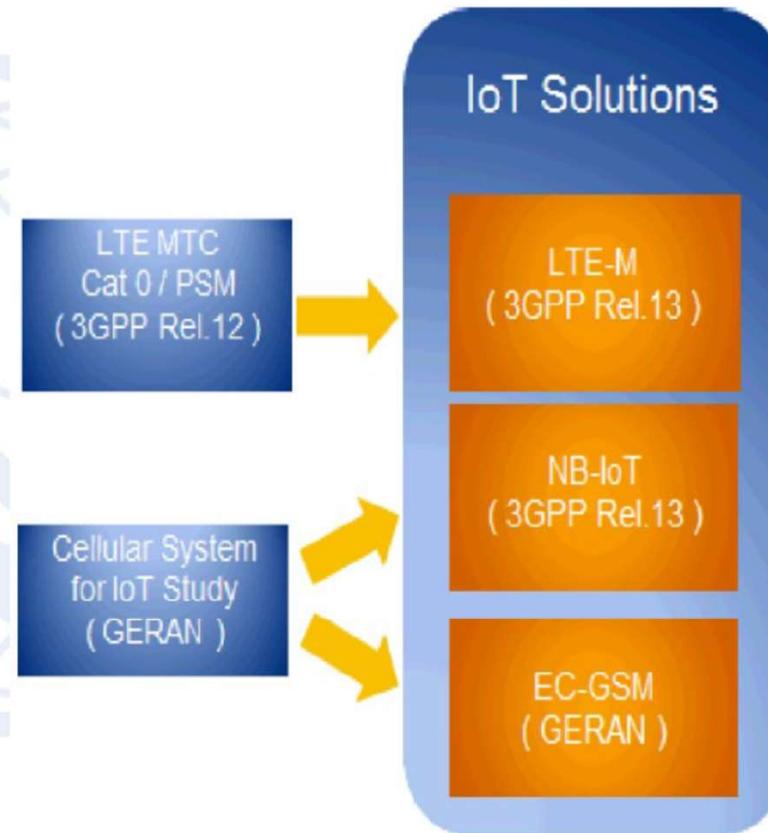


5G Evolution of 4G

DATA Terminal Equipment (DTE)



- **eMTC:** LTE enhancements for MTC, based on Release-12 (UE Cat 0, new PSM, power saving mode)
- **NB-IOT:** New radio added to the LTE platform optimized for the low end of the market
- **EC-GSM-IoT:** EGPRS enhancements in combination with PSM to make GSM/EDGE markets prepared for IoT



ETSI IoT radio interface standards and parameters

IoT standard	Generation	Downlink / Uplink Data Rate	Transmit power	Bandwidth	Modulation
EC-GSM	2G	474 / 474 Kbit/s	23 dBm	200 kHz	8-PSK
LTE-M Cat M1	4G	1 / 1 Mbit/s	23 dBm	1.08 MHz	OFDM (16-QAM)
NB-IoT-Cat NB1	4G	65 / 25 Kbit/s	23 / 14 dBm	180 kHz	OFDM - BPSK / QPSK

NB-IoT (ETSI 2017)

NB-IOT



Objectives

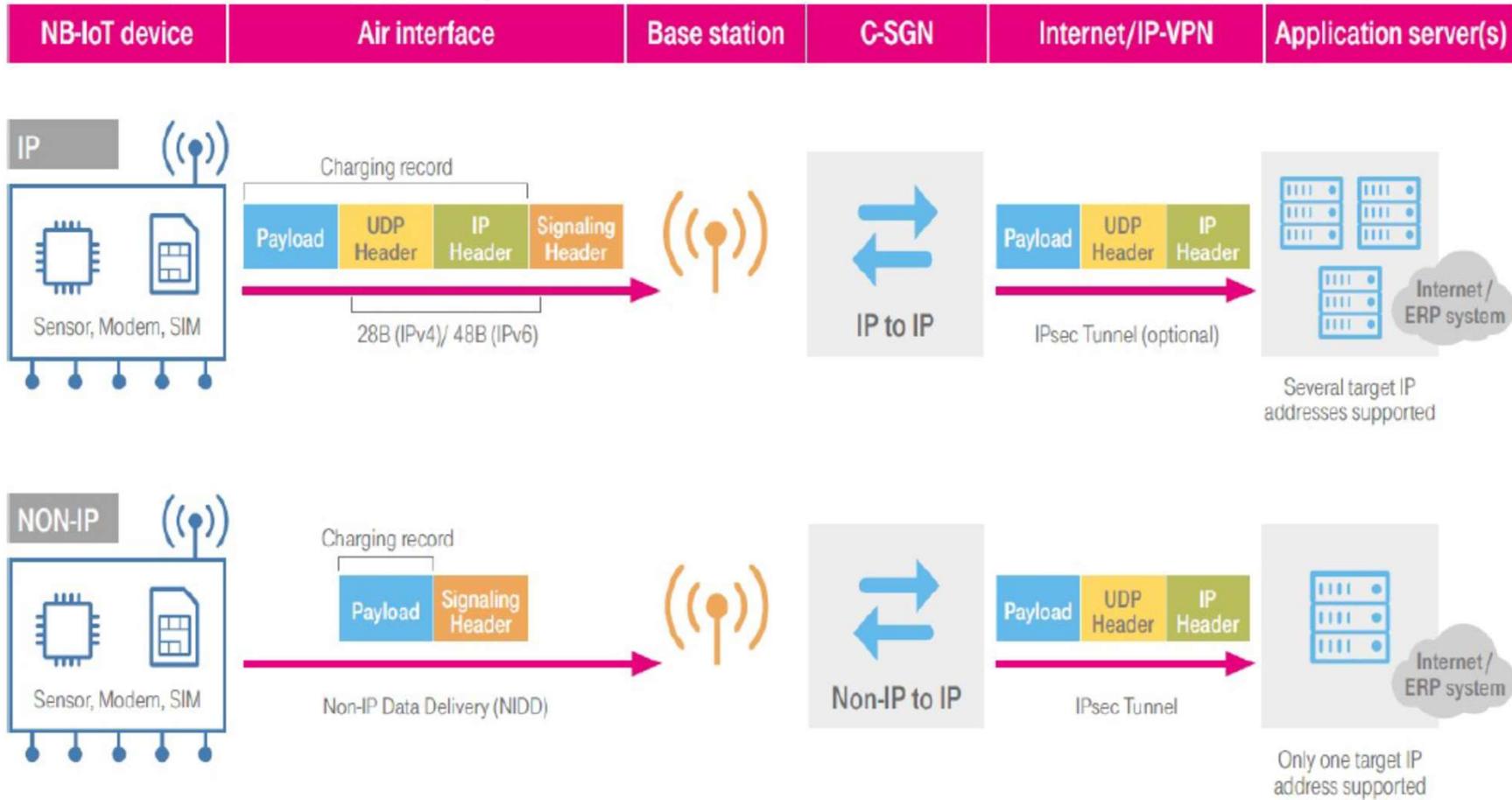
- Even lower cost than eMTC
- Extended coverage: 164 dB maximum coupling loss (at least for standalone)
- Long battery life: 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- Support for massive number of devices: at least 50.000 per cell

Main simplification

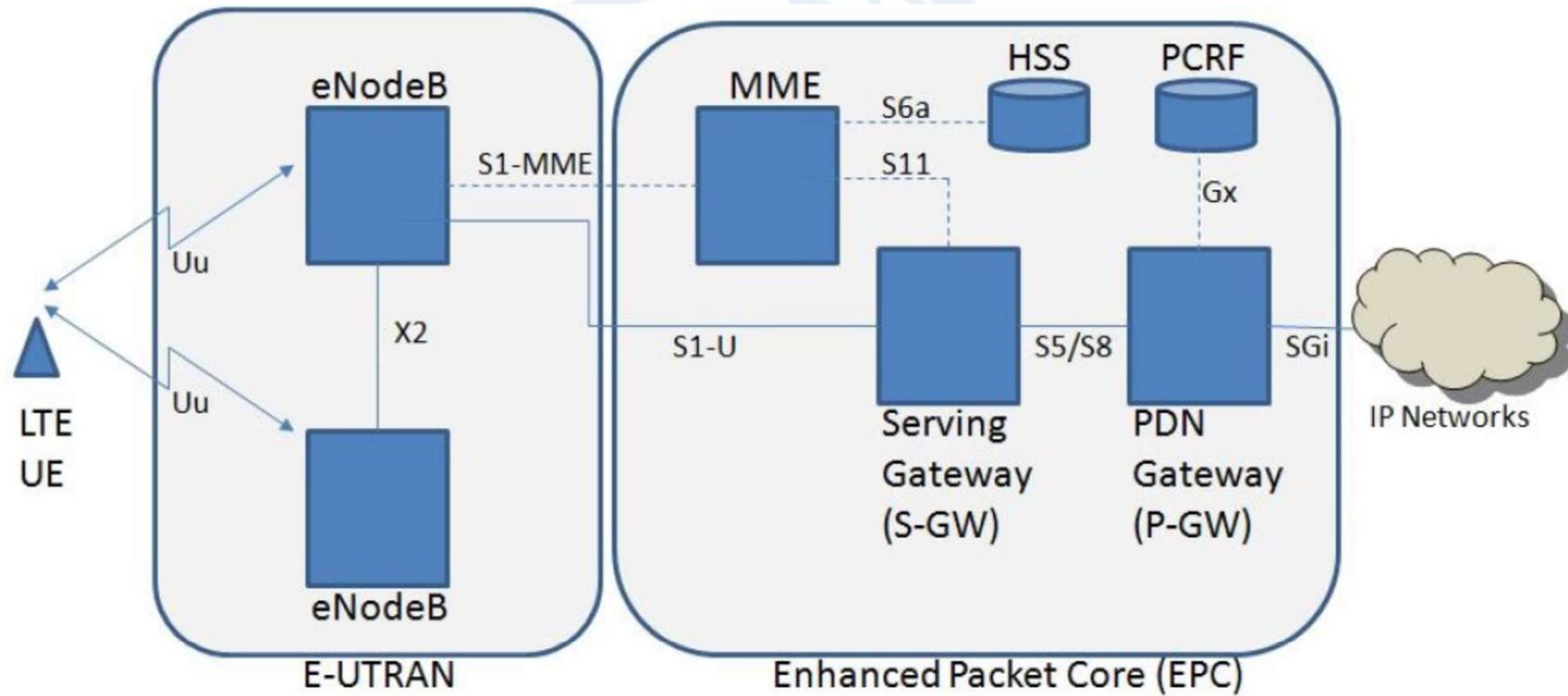
- Reduced data rate/bandwidth, mobility support and further protocol optimizations

NB-IOT supports 3 modes of operation:

- **Stand-alone:** utilizing stand-alone carrier, e.g. spectrum currently used by GERAN systems as a replacement of one or more GSM carriers
- **Guard band:** utilizing the unused resource blocks within a LTE carrier's guard-band
- **In-band:** utilizing resource blocks within a normal LTE carrier



Present LTE Architecture



Cœur de réseau de mobiles 4G :

- l'entité MME (*Mobility Management Entity*) a pour rôle de gérer : l'attachement des mobile; le suivi de la mobilité; l'établissement de sessions IP prenant en compte la politique de taxation de l'utilisateur; l'établissement d'un appel voix.

- l'identification, l'authentification et les droits d'accès du mobile sont gérées par l'entité HSS : l'entité MME interroge l'entité HSS pour pouvoir identifier le mobile en lui transmettant l'identité IMSI du mobile. Le HSS transmet à l'entité MME les données d'authentification. L'entité MME va ensuite réaliser la procédure d'authentification avec le mobile ;

- l'entité SGW (*Serving Gateway*) est le point d'ancrage des flux de sessions IP. Le SGW gère l'établissement d'un *bearer* (un tunnel IP de bout en bout associée à une qualité de service QoS). Le *bearer* s'établit du mobile jusqu'à l'entité PGW. Le SGW mesure le trafic consommé par utilisateur et, en cas de demande judiciaire, dérive le trafic (cas d'interception légale).

- l'entité PGW (*PDN Gateway*) est la passerelle de routage entre le réseau opérateur et un réseau IP (PDN : *Packet Data Network*). L'entité PGW réalise l'inspection de trafic, met en place les *bearer* avec le SGW, est en charge de fournir une adresse IP au mobile pour chaque *bearer*, mesure le trafic consommé et, en cas de demande, dérive le trafic dans le cas d'interception légale.

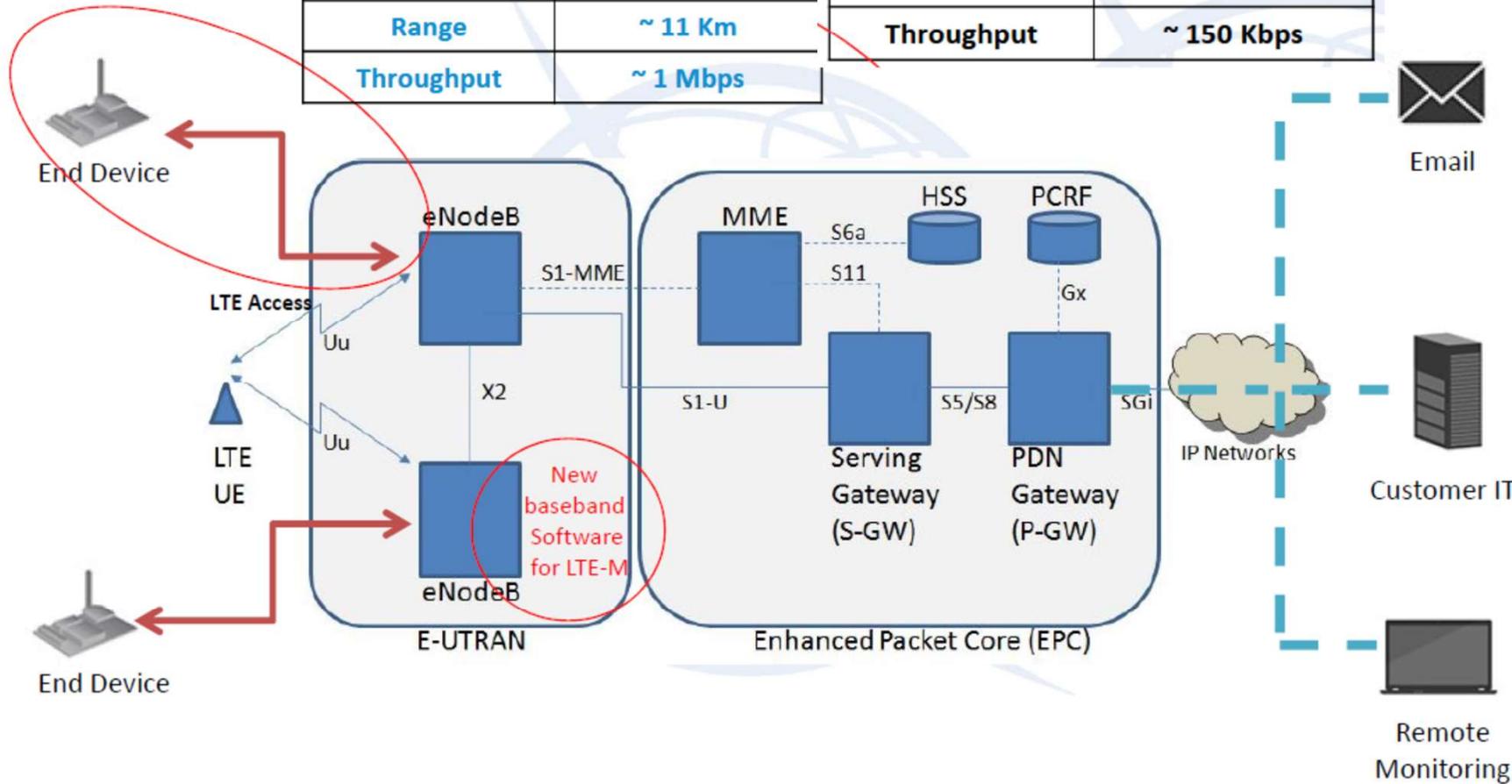
- l'entité PCRF (*Policy Charging Rule Function*) gère la mise en œuvre de la QoS pour les *bearer* dédiés et la gestion dynamique de la facturation.



Architecture



Frequency Band	Narrow Band	Frequency Band	Ultra Narrow Band
Access	LTE-M		
Range	~ 11 Km	Range	~ 11 Km
Throughput	~ 1 Mbps	Throughput	~ 150 Kbps

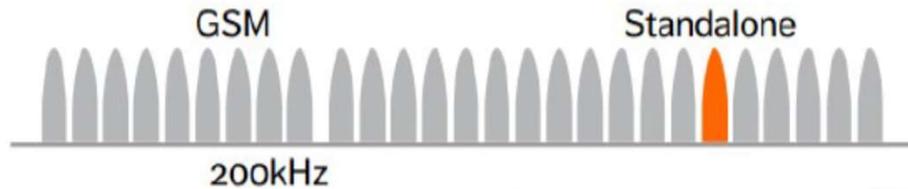




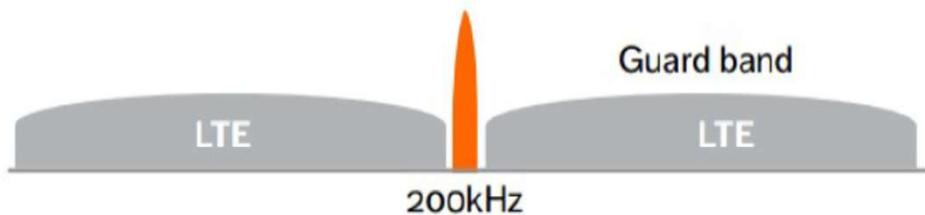
Spectrum and access



- Designed with a number of deployment options for **GSM** , **WCDMA** or **LTE** spectrum to achieve spectrum efficiency.
- Use **licensed spectrum**.



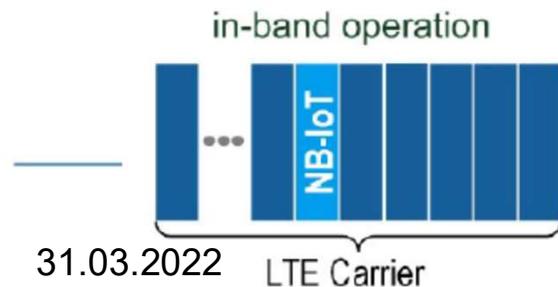
Stand-alone operation
Dedicated spectrum.
Ex.: By **re-farming GSM channels**



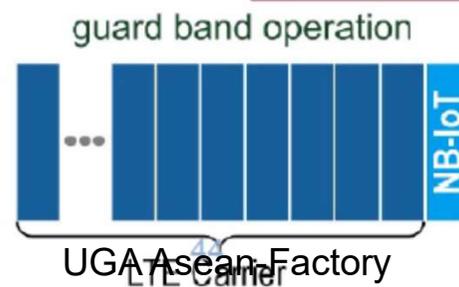
Guard band operation
Based on the unused RB within a LTE carrier's **guard-band**



In-band operation
Using **resource blocks** within a normal LTE carrier



31.03.2022

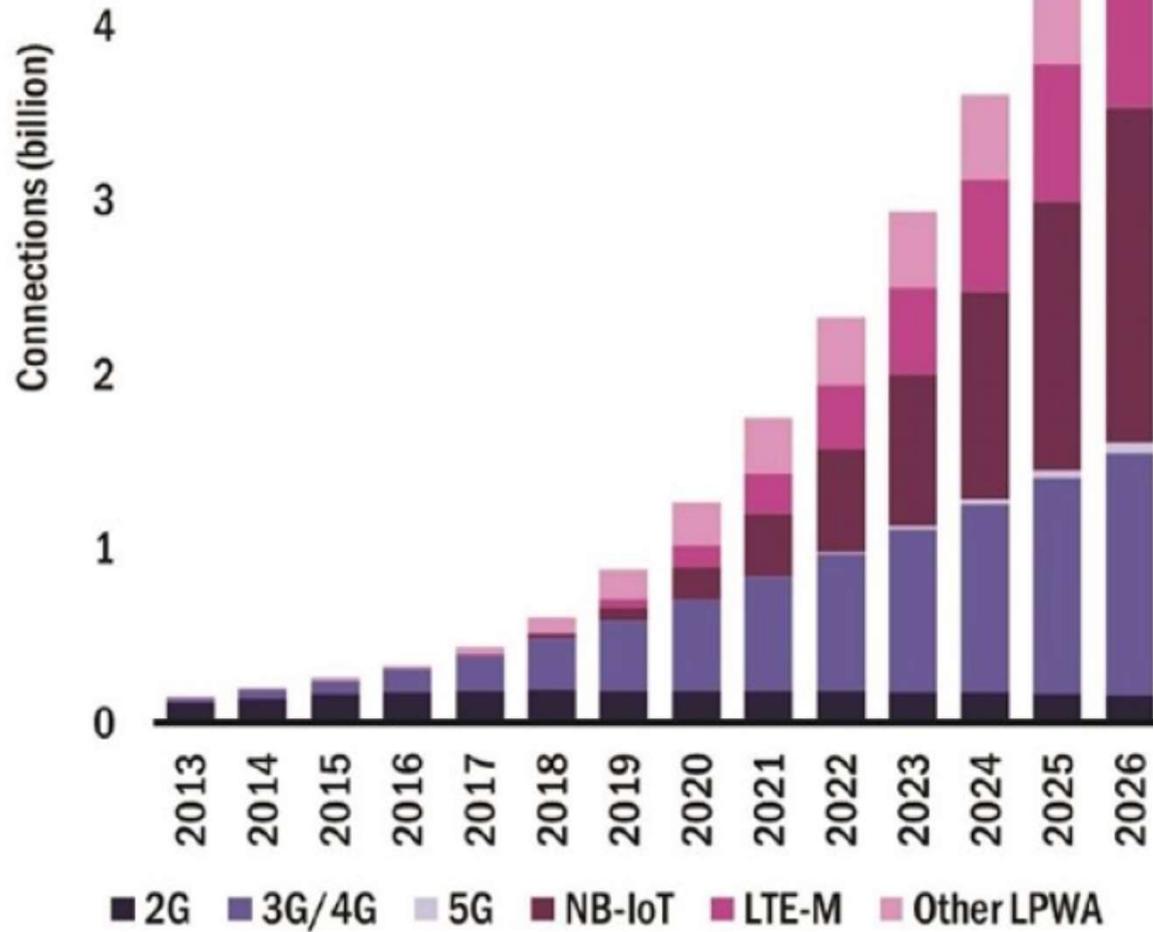


UGA Asean Factory



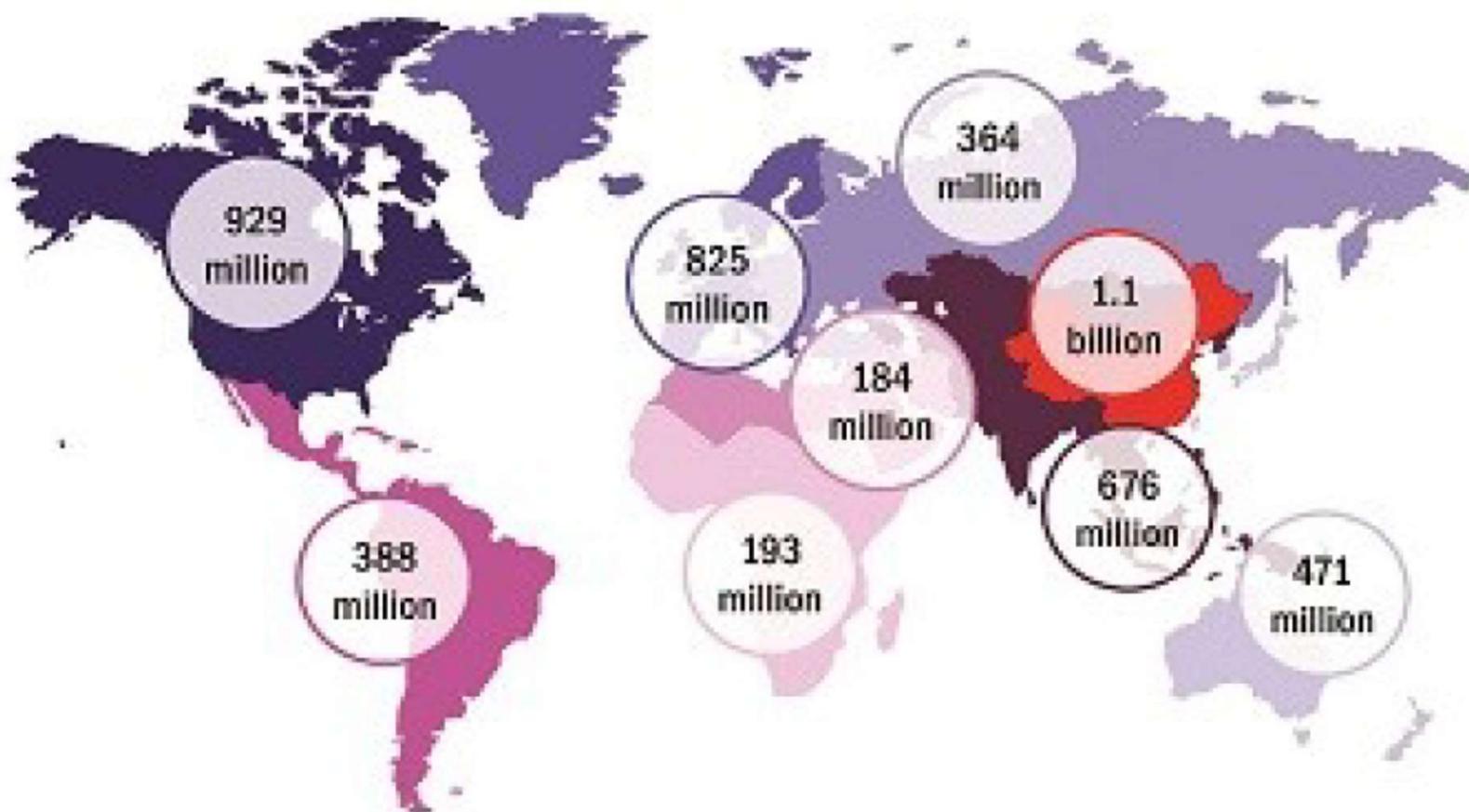


Future of IoT connectivity by network type across the world



NB-IoT will be the dominant network for IoT in 2026 (Analysys Mason)

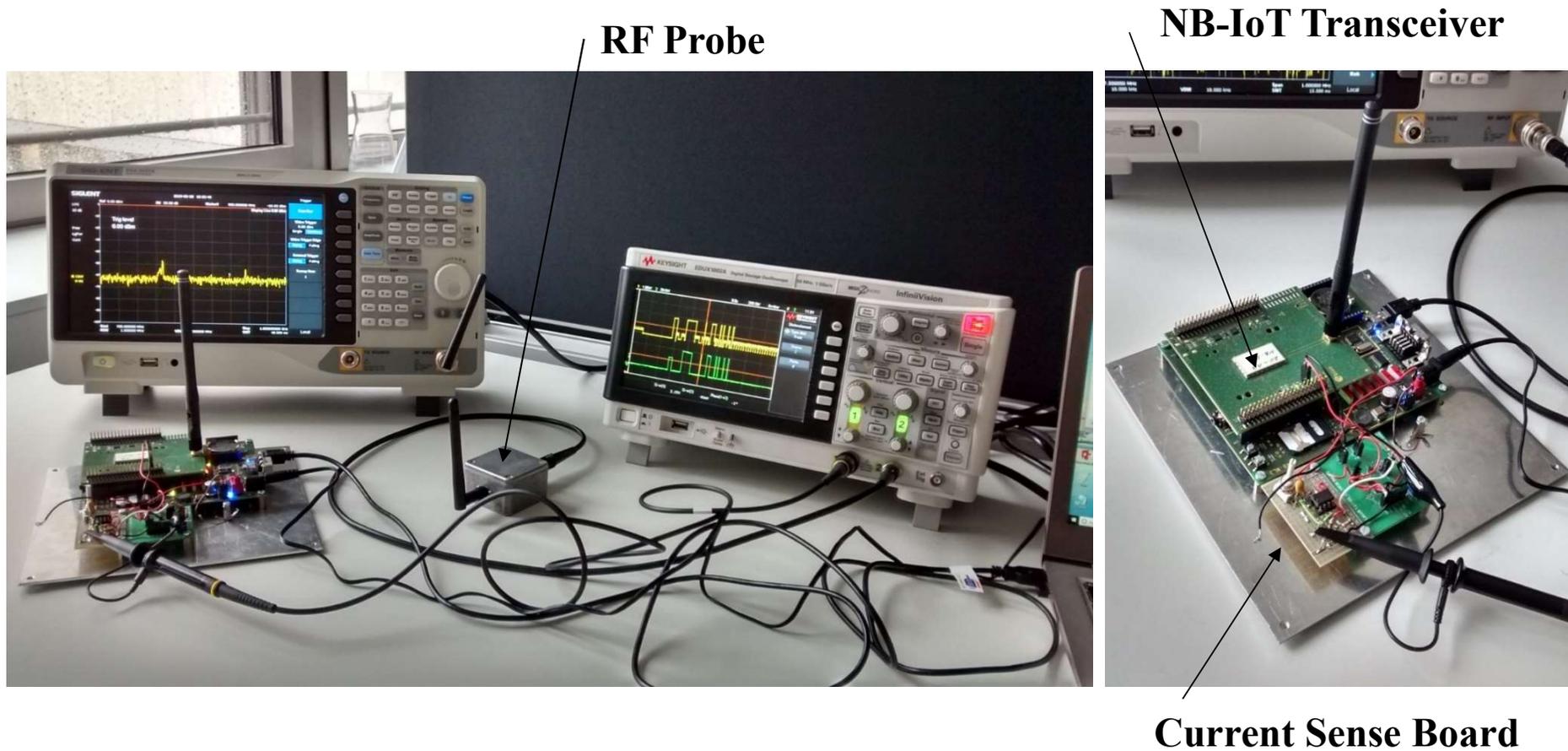




Total IoT connections (cellular and LPWA) by region, 2026

China will dominate the market by 2026 with 1.1 billion connections

Use Case: NB-IoT Low Power Modes and Power Consumption (IMEP)



Correlation of the power consumption ($V.I$) and the RF activity (V_{RF})

NB-IoT Modem control and configuration

Measurements with the 4G NB-IoT network 1NCE - Munich

SARA N211 : Tx 23 dB (13 dBm possible but not used) , maximum coupling loss 164 dB (not measured)

Send data to server with / without acknowledge

Send / Receive data to echo server

Modem control: AT commands

AT+NPING="208.67.222.222" ping OpenDNS DNS server,

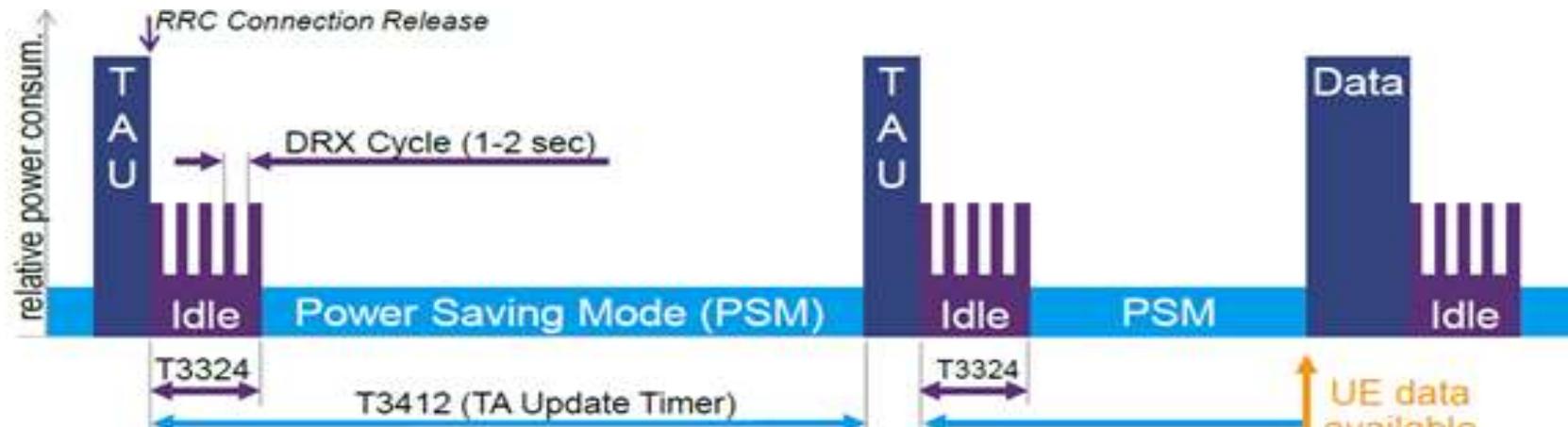
AT+NSOST=0,"195.34.89.241",7,5,"0102030405" data to Huawei Echo server,

AT+NUESTATS="ALL" modem status request

Software techniques for power optimization:

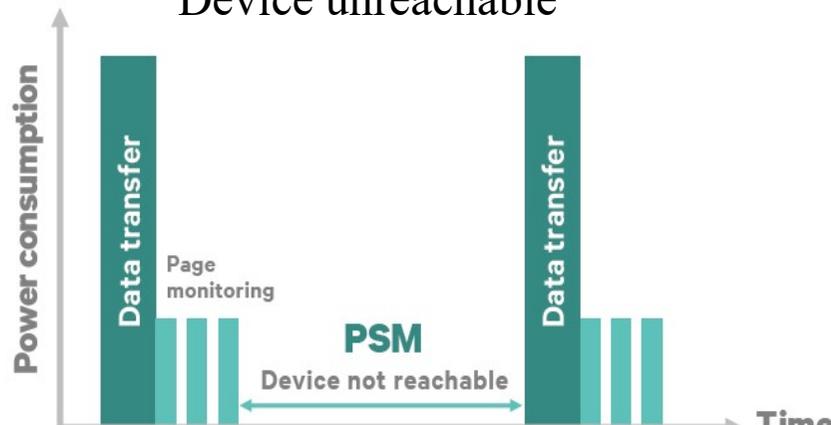
- eDRX (Extended Discontinuous Reception)
- PSM (Power Saving Mode)
- Release assistance

Power Saving Mode (PSM), eDRX



T3412 PSM
No paging / System OFF
Device unreachable

T3324 Normal Idle Mode
Monitoring paging

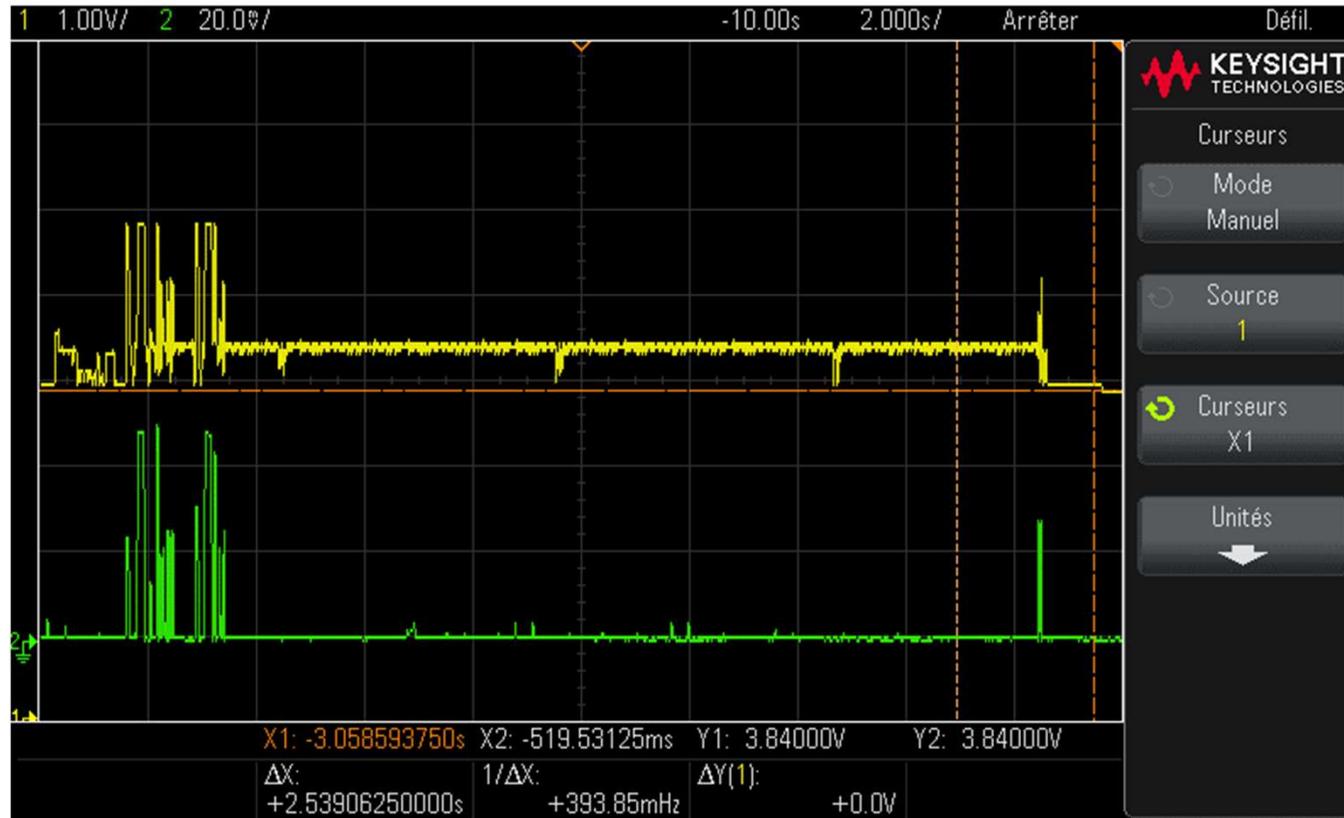


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UGA Asean-Factory

82

Normal data transfer



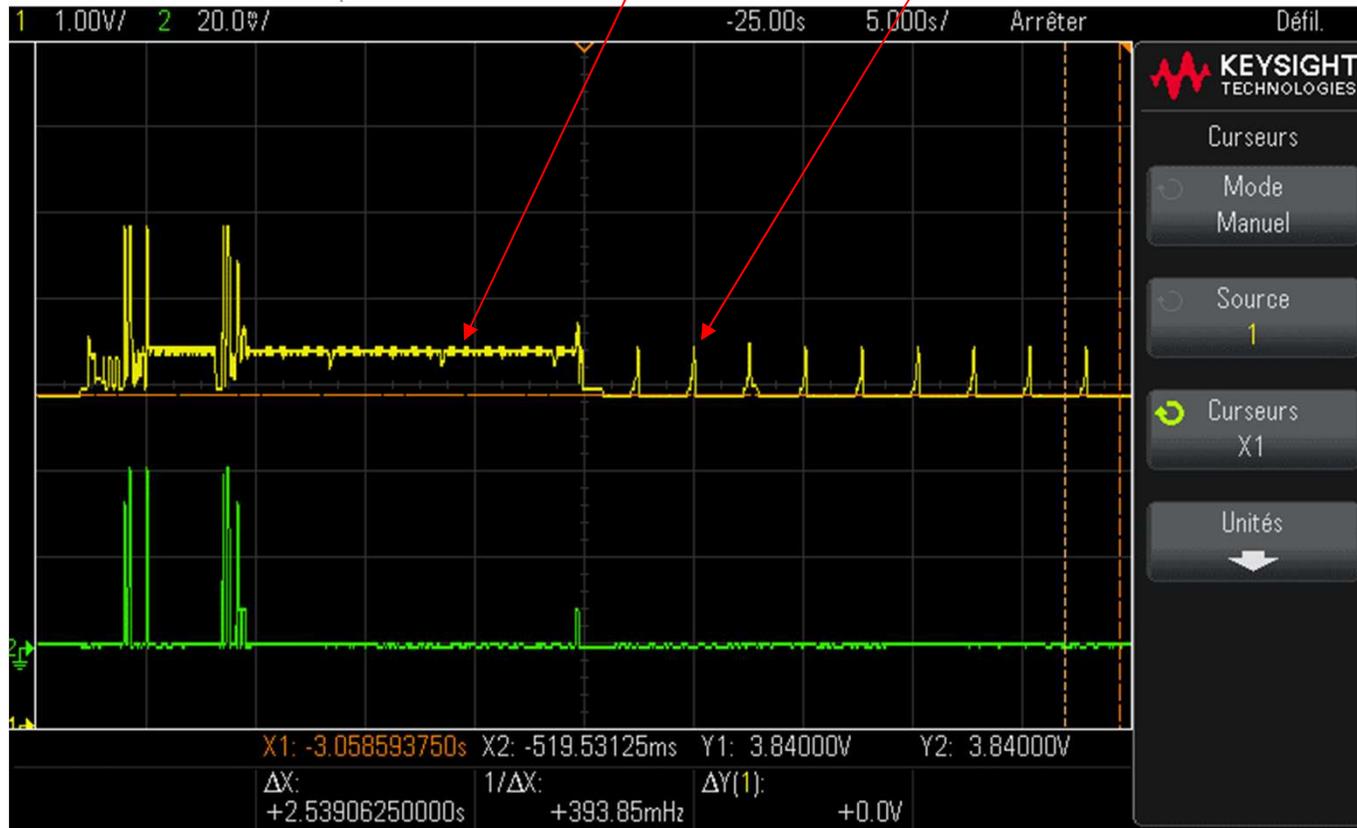
1000 μ Wh

UGA Asean-Factory

eDRX discontinuous reception

15s / 315 μ Wh

2.1 μ Ah / Rx ON
15s / 6x2.1 = 12.6 μ Wh



NB-IoT SARA N211 Modem Power Consumption

Standby	2.5 μ A	$V_{cc} = 3.8V$
Reset mode	2.1 – 8mA	
Active mode	6 mA	
Rx ON	20 mA	
Tx ON	23 dBm	200mA
	13 dBm	90m
Registration	50-200 mA	

Rx ON (100ms) 2.1 μ Wh
Tx ON (100ms) 21 μ Wh

128 bytes, AA battery 2500 mAh / 1.5V (3.75 Wh)
1000 μ Wh Standard mode
100 μ Wh Release Assistance mode

10 packets of 128 bytes / day – 10 years battery life time